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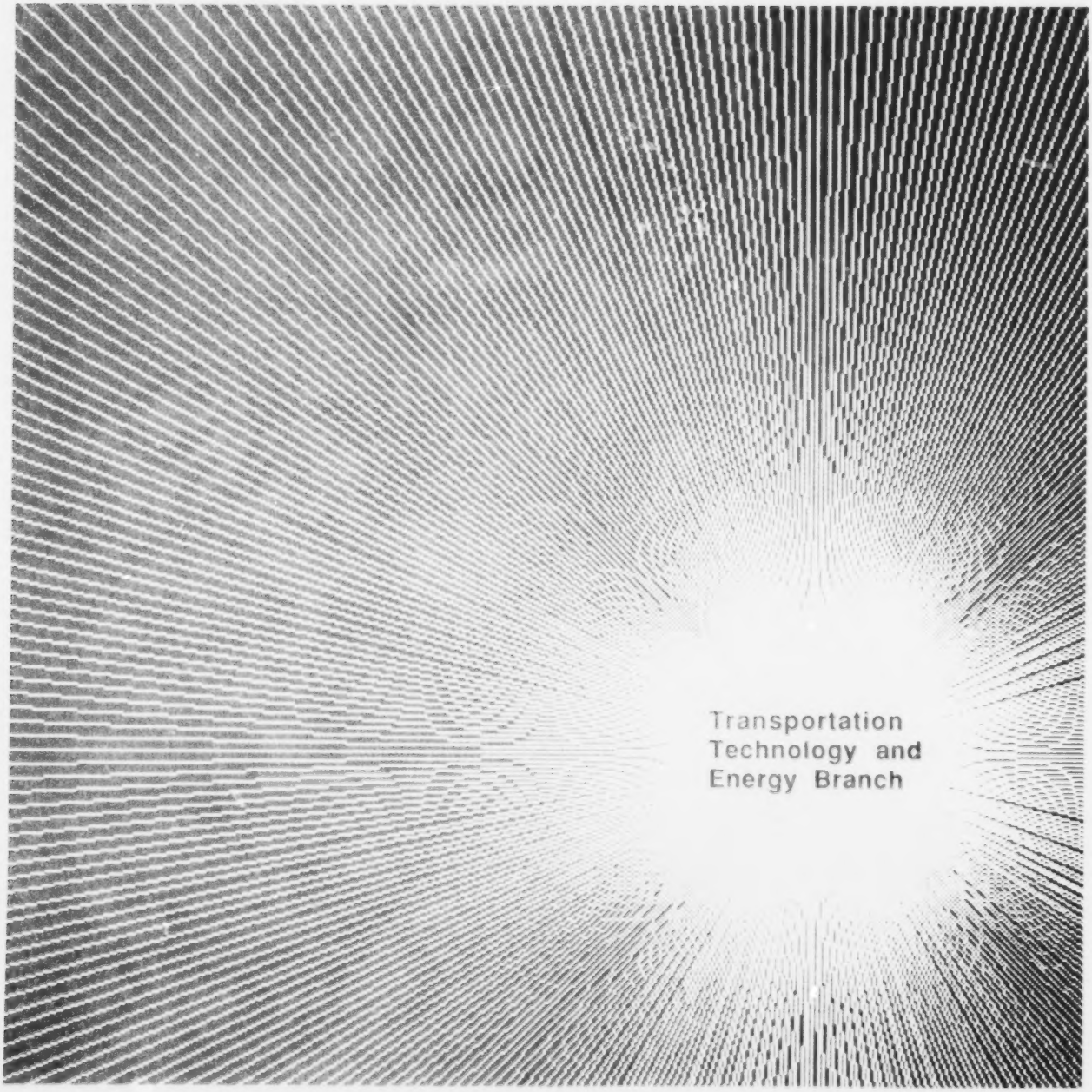

Natural Gas Bus Implementation at TTC's Lansdowne Garage

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Natural Gas Bus Implementation at TTC's Lansdowne Garage

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Abstract: The Vehicle Technology Office conducted a detailed investigation into the facilities and operations at the TTC's Lansdowne garage, with respect to the TTC's recent decision to implement natural-gas-powered buses at this location.

This report details the findings of the investigation, which are required to define the NG refuelling equipment and to forecast the impact on current operations.

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EXECUTIVE SUMMARY

The Toronto Transit Commission (TTC) recently made a commitment to purchase and operate natural-gas-powered buses. This decision necessitated a detailed investigation into the facilities and operations at the TTC's Lansdowne garage, where natural gas (NG) buses are to be first implemented. This report details the findings of the investigation, which provide the information required to define the NG refuelling equipment and to forecast the impact on current operations.

Staff from the Transportation Technology and Energy Branch of the Ministry of Transportation conducted a study of operations at the Lansdowne Garage during August 17-19, 1988, concentrating on diesel bus refuelling and servicing. An analysis of this data enabled the formulation of recommendations regarding NG refuelling facilities and bus queuing requirements.

The findings of the study are as follows:
- Average diesel fuel quantity delivered: 118 L/bus
- Maximum diesel fuel quantity delivered: 265 L/bus
- Maximum fuel delivery rate: 72.5 L/min
- Average refuelling time: 117 s/bus
- Average total service time: 211 s/bus

The TTC plans to introduce NG buses at the Lansdowne facility in three phases. The first phase will be the trial operation of two "concept" NG buses for about one year. The second phase will involve the gradual introduction of 25 "pre-production" NG buses and the eventual disposal of the two "concept" buses. Phase three of the project will consist of a continuation of the introduction of NG buses up to a total of 125, including the 25 buses from phase two.

Analyses of the findings led to the following recommendations:

- In the first phase, buses will be refuelled at a nearby commercial CNG fuelling station or a skid-mounted CNG compressor could be temporarily put on the site. In the second phase, a 1000 standard cubic foot per minute (scfm) compressor station plus a buffer will be installed. In the third phase, four 500-scfm compressors and an 8000 standard cubic foot (scf) buffer will be used.

- Service facility queuing area must be increased from current 30-bus capacity to 100-bus capacity.

- NG bus range was estimated at 585 kilometres (km) with roof-mounted tankage – adequate for maximum Lansdowne route length of 417 km.

- All available bus refuelling/servicing time must be used (6:00 p.m. to 5:00 a.m.), if all trolley buses are replaced by NG buses, otherwise a second servicing lane will be required.

Recognition of the above requirements should enable the satisfactory implementation of NG buses at the Lansdowne garage.

1/ INTRODUCTION

The TTC recently made a commitment to commission a fleet of 25 natural gas (NG) buses, which may be expanded to a total of 125 NG buses over a period of five years. The Lansdowne garage (on Lansdowne Avenue, north of Bloor St.) has been selected as home base for the first TTC NG buses.

The Transportation Technology and Energy Branch of the Ministry of Transportation of Ontario conducted a study and a detailed analysis of the existing Lansdowne garage on August 17-19, 1988. The impact of the proposed introduction of 125 NG buses on existing operations was forecast, and recommendations were made for new equipment, facility upgrades, and modification of existing operations.

This report documents the details of the study and the recommendations made to the TTC with respect to the operation of NG buses from the Lansdowne garage. The report findings provide information required for the definition of NG buses, refuelling facilities, and support equipment.

2/ DESCRIPTION OF LANSDOWNE FACILITY AND OPERATIONS

One hundred and fourteen electric trolley buses and 102 diesel buses operate out of the Lansdowne facility. They are all parked at the garage site except for 39 trolley buses, which are parked on a small lot located one street south, at Wade Avenue.

Both trolley and diesel buses, when finishing a route, enter the Lansdowne facility at the north-east corner of the garage. Trolley buses dispatched from the Wade yard, however, are returned there, unless repairs are required to the vehicle, in which case it is parked at the garage site.

Trolley buses entering the garage are directed to the appropriate parking lane (indoor or outdoor) by an inside "point man" (see site plan of facility, Figure 1). The trolley bus interiors are hand-swept once a day, while parked.

When entering the facility, diesel buses proceed through the garage to the servicing facility, situated on the west side of the parking lot. A lineup develops during the peak arrival time. The buses queue up, three to four abreast, in the space between the fence along the west property line and parking lane 22. Bus refuelling proceeds in the following manner:

1/ Bus drivers park their buses in queue as directed by an outside "point man";

2/ The point man drives the buses forward in the queue, space permitting;

3/ A "driver checker" inspects the bus interiors (for burnt out lights, etc.), picks up large garbage, and drives the buses into the servicing facility;

4/ A "fueller" attaches the refuelling hose to each bus, then checks engine fluid levels (oil and coolant) and detaches the refuelling hose after fill-up;

5/ While the bus is refuelled, the interior is cleaned by a "cleaner" using compressed air to blow dirt and debris toward the front of the bus, where it is sucked out of the bus by a "cyclone" positioned over the front door;

6/ Two "parkers" take the buses from the servicing facility, out onto the street, north through lane 3 of the garage to the washer. The buses are then parked in the designated parking lane (either inside or outside the garage).

This procedure is followed during the peak refuelling time between 6:00 and 9:00 p.m. During the night shift, from 12:00 to 3:00 a.m., essentially the same procedure is followed, but with fewer staff.

Parking location inside the garage is determined by more than just the type of bus (trolley or diesel): lane 7 is reserved for trolley buses requiring major repairs; the newest diesel buses, which are assigned all-day runs, are parked in lane 8; and lanes 9 and 10 are reserved for diesel buses requiring repairs.

The information from the shift foreman on buses requiring repairs or scheduled maintenance is relayed to the parkers via the servicing facility staff. Buses requiring major repairs are specially designated for swing runs the next day to free them for maintenance during the day.

3/ DESCRIPTION OF OPERATIONS MONITORING

The study of refuelling operations at Lansdowne took place over a three-day period. Diesel and trolley bus arrival, fuel pump queuing, and parking were monitored from 5:30 p.m. to 3:30 a.m., Wednesday, August 17 through Friday, August 19.

At the entrance to the facility, bus number and entry time were recorded for each bus, as well as whether it was a trolley or diesel. At the refuelling and servicing facility, the following information was recorded for each bus:

- bus number;
- fuel delivery time;
- bus entry time;
- fuel quantity delivered;
- total servicing time.

Data from the three days of observations were assembled for analyses (see Table 2). This information was then plotted to illustrate the characteristics of the refuelling operation.

The purpose of the study was to obtain information in the following areas:

3.1/ Total Fuel Delivery

The average and peak quantities of diesel fuel delivered at Lansdowne were needed to estimate the NG fuel tankage requirements for the Lansdowne bus fleet. This may be insufficient for future use on routes supported by other TTC garages and will have to be calculated again when NG buses are implemented elsewhere.

3.2/ Fuel Delivery Rate

The maximum fuel delivery rate for the Lansdowne diesel pumps was required so that NG compressor facilities could be sized. In sizing NG compressors, it is desirable to match the diesel delivery rate on an energy basis. The NG energy delivery rate is also dependent upon the efficiency of the NG bus relative to the diesel. In other words, if the NG bus consumes more energy than the diesel bus under identical operating conditions, then the NG delivery rate must be increased by the same percentage.

3.3/ Impact of NG Buses on Bus Queuing

During the study of operations at Lansdowne, approximately 85 diesel buses and 85 trolley buses were dispatched daily. The diesel refuelling facility is unable to match the rate of bus arrivals during two periods of the day. During these periods, a line-up or queue builds up at the entrance to the refuelling (servicing) facility.

Currently no trolley buses are involved in this queue. If trolley buses are gradually phased out, replaced by NG or diesel buses, much larger queues will result at the entrance to the servicing facility. The potential impact on queue size must be determined in order to plan the changes that may be required to existing lot partitioning and operations.

4/ OBSERVATIONS

Refuelling data for a total of 285 diesel buses were obtained (see Table 2) over a period of three days. The average performance figures for the fuelling operation were as follows:

- Diesel fuel delivered: 118.3 L
- Refuelling time: 116.5 s
- Total servicing time: 210.9 s
- Dwell time (non-refuelling service time): 89.6 s
- Fuel delivery rate: 60.9 L/min

4.1/ Servicing Frequency

Bus servicing frequency over the three-day period was tabulated (Figure 2) to illustrate how often individual buses were refuelled. A small fraction of buses were serviced once (6 buses) or five times (2 buses). The majority (55 buses) were serviced three times, while the remaining third were serviced either two (17 buses) or four (21 buses) times over the three days.

Since all available buses are serviced daily, it would be expected that a given bus would be serviced three times over a three-day period. Those buses serviced four or five times had likely been sent out as charter buses or change-offs (a bus dispatched to replace one in service) after revenue service operation and servicing the same day. These buses would return to the garage for a second servicing on the same day. Buses refuelled fewer than three times may have been towed in for maintenance, not dispatched, or missed being serviced altogether on one or more days.

4.2/ Fuel Quantity Delivered

Figure 3 is a frequency distribution illustrating the number of buses dispensed a given quantity of fuel. Figures 3a through 3c describe fuel dispensing on each of the three days, and Figure 3d for the three days combined.

It must be noted that the figures obtained from this study are specific to TTC's Lansdowne garage only, and that fuel delivery rates and quantities are not to be taken as TTC fleet averages.

On each of the three days a double peak in the histogram is formed, the first at about 75 litres and the second at about 145 litres. The first peak probably results from buses operating in "tripper service" (relatively few operating hours) while the second is most likely due to buses in all-day service.

Peak consumption was 265 litres, representing 58% of the total (typical) fuel capacity of a 40-foot transit bus (453.6 litres or 100 imperial gallons).

One bus, serviced on August 17, consumed 345 litres – far more than the peak of 265 litres, which was defined over all three days. Since this consumption occurred only on one day of the three days, it is not characteristic of a single route and indicates that this bus missed refuelling one day.

Figure 4 is a cumulative distribution of fuel delivered over all three days. The y-axis represents the percentage of buses that consumed the amount of fuel indicated on the x-axis, or more. Note that 90% of the buses required 185 litres (41% of tank capacity) or less.

4.3/ Fuel Dispenser Delivery Rate

Figure 5 compares the number of buses refuelled at a given diesel pump delivery rate. Peak delivery rate is approximately 72.5 L/min. The peak delivery rate is important because this is the delivery rate that the CNG compressor must match.

The broad range of delivery rates observed indicates that maximum delivery was not always selected for each bus. Some buses were more sensitive than others to "splash-back" during refuelling and a lower delivery rate was often selected to prevent premature shut off of the automatic filler nozzle. This accounts for the lower average delivery rate of 60.9 L/min.

4.4/ Bus Servicing Time

Figure 6 illustrates the distribution of buses over a range of total service times. Total service time is the time that the bus was at the service island, including drive-in and drive-out. Servicing consists of refuelling, internal cleaning, fluids check, and light maintenance.

Minimum service time was about 115 seconds, although one bus did appear in the 95-second interval. Figure 7, a cumulative plot of the same data, indicates that 90% of the buses required 275 seconds or less. The required service time for most buses was between 115 and 275 seconds (1.9 to 4.6 minutes). Average service time was 210.9 seconds (3.5 minutes).

To determine the relationship between service time, refuelling time, and fuel delivered, a least-squares regression was performed on the data (see Figure 8). The lower line in Figure 8 represents the refuelling time as a function of fuel delivered and the upper line represents total servicing time. The y-intercept of the total servicing time line represents the time required to service the bus if no fuel were delivered (145 seconds). The time is required for cleaning, fluid checks, and vehicle shuttling in and out of the facility.

Total service time and refuelling time both increased with total fuel delivery. The slope of the total service time line is shallower than that of the fuel delivery time. This

indicates that as more fuel is delivered, the total service time is comprised more of the refuelling time and less of the dwell time (dwell time is defined as the non-refuelling service time).

Maximum dwell time of 118.8 seconds occurs at a minimum fuel delivery of 5.7 litres. As the amount of fuel delivered (and hence the total service time) increases, dwell time decreases. Minimum dwell time of 62.5 seconds occurs at a maximum fuel delivery of 264 litres.

The fuel delivery time was not zero, at zero fuel delivery, because a minimum amount of time is always required by the refuelling operation. If the automatic fuel shut off releases the trigger unusually early, the attendant will usually operate the nozzle manually for a short time to verify that the tank is completely full. This minimum time was estimated at 24.6 seconds by the regression analysis.

4.5/ Bus Queuing

Figure 9 (a through c) indicates the number of diesel buses awaiting servicing between 5:00 p.m. (17:00) and 3:00 a.m. (03:00) the following morning for each of the three days monitored. This is when most diesels are serviced (typically 5 to 10 are serviced between 3:00 and 5:00 p.m. as well).

As indicated in the figures, greatest diesel bus queuing activity took place between 6:00 and 8:30 p.m. A few periods of activity occurred later on, however these were relatively insignificant. The queue peaked at 7:30 p.m. each evening. Queue peaks were 20, 27, and 24 buses.

Figure 10 (a through c), indicates the arrival of trolley buses at the Lansdowne garage and Figure 11 (a through c) the impact on the servicing queue, if these buses had required refuelling. Fewer trolleys arrived at Lansdowne than diesels, partly because the Wade yard was also filling up with trolleys during this time. The arrival of trolley buses at the Wade yard was not recorded, but TTC staff explained that the Wade yard usually fills up relatively early in the evening.

To simulate the impact of the Wade trolleys also being replaced by NG or diesel buses, another 39 buses were added to the servicing queue from 6:00 to 8:00 p.m. A constant arrival rate of 20 buses per hour was used in the absence of arrival data for the Wade-bound buses.

Figure 11 (a through c) illustrates the forecast queue size during the evening shift, during which all buses must be serviced prior to parking. As Figure 11 indicates, a queue capacity of at least 95 buses will be required if all trolley buses are replaced by

new NG-powered or diesel-powered equipment. This is a significantly larger queue than the current facilities can accommodate – typically 20 to 30 buses (see Figure 9).

To determine whether or not the existing bus servicing times are quick enough to handle every bus dispatched during the day, another queue was considered. As before, the queue of all buses was considered at the service entrance. This time buses were artificially processed (by computer simulation) at the rate of 17 buses per hour (corresponding to the average servicing time of 3.52 minutes per bus). These results are illustrated in Figure 12 (a through c).

As indicated in Figure 12, the existing service is capable of processing all buses dispatched during the day by 5:00 a.m. Therefore, a single lane service bay may be retained provided that the NG refuelling operation is no longer than the current diesel refuelling operation. A change in operation is required – bus servicing will have to continue all night, without stopping.

4.6/ Route Characteristics

Differences in fuel consumption between typical trolley and diesel routes must be considered because of the potential impact on bus range requirement. Since diesel buses are free to operate on any route in the TTC system, average fuel economy will reflect higher (suburban) and lower (urban) operating efficiency. The trolleys, however, are restricted to urban routes, which result in lower fuel efficiency. Therefore for a given length of route, more energy could be required on a typical trolley bus route than an average diesel route (possibly necessitating more fuel storage capacity on NG buses dispatched to current trolley routes). An actual estimate of the energy consumption of trolley versus diesel routes was not available at the time of writing.

At Lansdowne, the average route length is greater for diesel buses than for trolleys. Diesel route length averaged 127 km (range from 10 to 417 km). Average trolley bus route length was 119 km (range from 27 to 394 km). Because the average trolley route length is about 6% shorter than that of the diesel, this tends to offset the fuel economy penalty which would be expected on those routes. For the purposes of this study, it was assumed that equal energy would have been required to service a trolley or diesel route of a given length.

4.7/ NG Bus Definition

The NG bus must integrate into existing bus operations with minimal impact. Bus range and refuelling time have been identified as two of the key constraints to be defined. Refuelling time will be specified in the design of the CNG (compressed natural gas) compressor station to ensure that all buses can be refuelled within the available time.

The bus-mounted refuelling components, such as lines and valves, must be sized to complement the compressor. Bus range, however, is completely dependent on bus design. Fuel tanks of adequate size and an engine with acceptable power rating, durability, and efficiency must be specified. As indicated in Figure 3d, the maximum daily diesel fuel consumption measured over three days was 265 litres or less. At an average fuel economy of 53.7 km/L (5.25 mpg), this corresponds to a range of 495 km (308 miles). This figure was taken as an estimate of the minimum range required by buses operating out of the Lansdowne facility.

The above estimate of minimum range required by Lansdowne's buses is somewhat greater than the maximum route length identified above in Section 4.6, Route Characteristics (495 km compared to 417 km). The difference is probably due to the fact that 5.25 mpg is a typical fleet average fuel mileage. The buses based at Lansdowne are operated at a relatively low average speed, have greater than average passenger loading, and probably have a more than average number of stops per mile. If the fuel consumption based on the maximum range specified above in Section 4.6 is calculated (along with the maximum fuel consumption), an average of 4.44 mpg is obtained.

It is important to recognize the difference in fuel economy of the Lansdowne buses relative to the rest of the fleet. The 585-km range obtained in Table 1 becomes 495 km if corrected for this difference in fuel mileage (compared to 417 km required – Section 4.6).

The bus manufacturer proposes to mount the CNG fuel tankage to the vehicle roof structure. The proposed tankage consists of four 330-mm (13-inch) diameter by 6096-mm (20-ft) long aluminum composite cylinders, mounted longitudinally to the bus roof structure. Total CNG storage is estimated at 400 m^3 (14 127 scf) – equivalent to the energy of 393 litres (86.7 gallons) of diesel fuel at a CNG storage pressure of 3000 psig.

Due to the lower energy efficiency of the NG-powered bus, relative to the diesel (see Table 1), NG bus range is about 20% less than the diesel for a given quantity of energy. When bus efficiency is considered, the proposed CNG tankage is equivalent to approximately 314 litres (69.4 gallons) of diesel fuel, providing a range of 585 kilometres.

The estimated range of the NG-powered bus at 585 kilometres is more than adequate for the longest routes serviced by the Lansdowne garage, which are estimated at under 500 kilometres. Therefore the proposed CNG tankage is adequate for the intended service.

5/ COMPRESSOR STATION DEFINITION

The introduction of NG buses into the Lansdowne facility is proposed to take place in three phases. The first phase will be the trial operation of two "concept" NG buses for about one year. These first buses will give the TTC hands-on operational experience with NG buses.

The second phase of the project will involve the gradual introduction of 25 "pre-production" NG buses and the eventual disposal of the two "concept" buses. Phase three of the project will consist of a continuation of NG bus introduction, up to a total of 125. Note that these recommendations are for the assumptions stated only.

5.1/ NG "Concept" Bus Demonstration

The first two NG "concept" buses will be 96 inches wide, equipped with "first generation" NG engines and roof-mounted NG fuel tanks. Refuelling the two trial NG buses will be accomplished in one of two ways: buses could be driven to a nearby commercial CNG fuelling station, or a skid-mounted, CNG compressor (50-100 scfm) could be put on site at Lansdowne as a temporary refuelling facility.

While the first option would be simpler, it would also be much less convenient from an operations perspective. A suitable commercial station would have to be found and arrangements with respect to refuelling times would have to be worked out. Also, TTC's operations personnel would learn little about NG bus refuelling and compressor station operation.

A skid-mounted compressor would provide convenience and operating experience, however the availability of such a station, in such a short time period and the potential problem of disposing of it after about one year could create significant problems.

5.2/ 25-NG-Bus Demonstration

The introduction of 25 NG buses at Lansdowne garage will require additions and changes to existing facilities there. A permanent refuelling station will be necessary as well as upgrades to bus storage, maintenance, and service queuing operations.

A compressor station rated at a minimum of 1510 scfm (see Appendix A) is required for 125 buses. A facility of reduced capacity would be acceptable for the operation of 25 buses, since extra time is available during the evening to accommodate servicing of the additional buses (8:00 p.m. to 11:30 p.m. and from 3:30 a.m. to 6:00 a.m.). It is proposed that a compressor station be sized to accommodate the smaller NG bus fleet, with the provision to expand the station for the full 125-bus operation. This may be accomplished by employing four 500-scfm compressors with only two 500-scfm compressors installed for the 25-bus operation.

It is probable that the first 25 NG buses will replace trolleys, therefore the number of buses queuing up for servicing will steadily increase with NG bus introduction (since trolleys are not currently serviced at the diesel bus servicing facility). Installation of two of the proposed four 500-scfm compressors would provide approximately 66% of the recommended rated delivery. The estimated average servicing time for the 25 buses would be 4.08 minutes per bus (Appendix C) with the smaller refuelling facility. At this rate, the total additional servicing time for the 25 buses would be 1.70 hours.

Approximately six hours of diesel bus servicing time are currently not being used (during the 6:00 p.m. to 5:00 a.m. service period). Some of this time could be used to service the additional NG buses, however minor changes to existing operations may have to be made.

The use of four identical NG compressors necessitates only one set of replacement parts to be stocked. The 25-NG-bus demonstration would proceed with only two 500-scfm compressors, but the station itself would be designed to accommodate four to satisfy requirements of the 125-NG-bus fleet.

5.3/ 125-NG-Bus Operation

The compressor station, sized for 125 buses should consist of four 500-scfm compressors and a buffer tank, configured as illustrated in Figure 13, to balance compressor loading during the refuelling cycle. The buffer stores the compressed gas when the dispenser is not delivering to the bus. The buffer enables the compressors to be used more effectively and extends compressor life by reducing the number of starts and stops during the refuelling operation. Gas stored in the buffer supplements compressor delivery during refuelling, effectively reducing required capacity.

A buffer of approximately 8000 scf will enable the dispenser, backed by four 500-scfm compressors to exceed the fuel delivery performance of the existing diesel refuelling operation (see Appendix A). Operation on only three compressors (for maintenance of the fourth) will enable bus refuelling at rates only slightly below those of the diesel dispenser.

6/ CONCLUSIONS

1/ It is not practical to install permanent NG refuelling facilities at Lansdowne for the two-bus "concept" demonstration. Either a skid-mounted (temporary) compressor should be put on site or arrangements with a commercial refuelling station should be made.

2/ The 125-NG-bus operation will require four 500-scfm compressors and a 8000-scf buffer. The station will enable refuelling at rates close to that of the diesel pumps with one compressor shut down for maintenance.

3/ A down-scaled permanent compressor facility is recommended for the 25-NG-bus operation, based on the four 500-scfm compressor station mentioned above. Two 500-scfm compressors should be installed in a facility that is capable of housing four in the same building.

4/ The NG buses with the recommended tankage on board will have sufficient range to handle the longest routes serviced by the Lansdowne facility.

5/ As trolley buses are phased out in favour of NG buses, changes in bus handling practices will be required. Increasingly larger queues will result at the entrance to the servicing facility, necessitating revised parking procedures and a re-allocation of space.

6/ Recognition of the requirements described in this report should enable the satisfactory implementation of NG buses at the Lansdowne garage from a technical perspective. This is, however, not an ideal location at which to base a new technology such as NG buses. Close proximity to residential areas, cramped conditions, and the presence of trolley bus overhead wiring make this a relatively difficult facility to upgrade for NG buses.

Table 1/ Natural Gas Equipment

	Diesel	Natural gas
Energy Consumption		
Proposed Bus Fuel Storage Capacity	100 imp. gal * 453.6 L	14,127 ft^3 400 m^3
Total Energy Content of Vehicle Fuel Storage System	15 300 MJ	13 265 MJ
Relative Vehicle Efficiency	100%	80% **
Average Estimated Bus Energy Consumption	5.25 mpg 0.0551 km/MJ	25.7 mi/1000 ft^3 0.0441 km/MJ
Estimated Range	845 km	585 km
Refuelling		
Average Bus Refuel time	1.94 min	1.94 min
Average Bus Total Service Time	3.52 min	3.52 min
Average Fuel Delivered	118.3 L 4000 MJ	5325 ft^3 5000 MJ
Average Fuel Delivery Rate	60.9 L/min 2060 MJ/min	2743 scfm 2575 MJ/min
Minimum Compressor Capacity (to match average diesel delivery)		1510 scfm+
Minimum Compressor Capacity (to match worst delivery condition)		2636 scfm++
Proposed Compressor Configuration		2000 scfm (4 x 500 scfm)

* - typical
** - 13% engine efficiency penalty
plus 7% weight penalty relative to diesel
\+ - buffer tank installed (see appendix A)
++ - 0 psig initial bus tank pressure
all compressor capacities specified at 75 psig
NG supply and 3600 psig delivery pressure

Table 2/ Analysis of Data

DATE	AER #	BUS #	QUEUE ARRIVAL H : M	FUEL ARRIVAL H : M	QUEUE TIME	----TIME----- FUEL ONLY MIN:S	TOTAL CYCLE MIN:S	FUEL AMOUNT (L)	FUEL TIME (SEC)	TOTL TIME (SEC)	DWELL TIME (SEC)	AVG FUEL DELV RT (L/MIN)	REGR LINE FUEL TIME	REGR LINE TOTAL TIME
17	1	8873	:	6 : 6	-	2 :32	3 :59	176.7	152	239	87	69.8	162.4	244.0
17	2	8862	:	6 : 9	-	1 :13	2 :35	85.2	73	155	82	70.0	91.1	192.6
17	3	8855	6 : 11	6 :12	1	2 :24	6 :56	165.2	144	416	272	68.8	153.5	237.5
17	4	8878	5 : 42	6 :19	37	1 : 8	2 : 2	57.9	68	122	54	51.1	69.8	177.2
17	5	7962	5 : 49	6 :21	32	0 : 5	1 :37	5.7	5	97	92	68.4	29.1	147.9
17	6	8532	5 : 56	6 :23	27	1 :12	2 : 6	86.0	72	126	54	71.7	91.7	193.0
17	7	7752	6 : 14	6 :25	11	1 :56	4 :30	128.8	116	270	154	66.6	125.1	217.0
17	8	8868	6 : 23	6 :28	5	1 :41	3 :27	72.8	101	207	106	43.2	81.4	185.6
17	9	7349	6 : 23	6 :33	10	0 :50	2 :26	57.9	50	146	96	69.5	69.8	177.2
17	10	7354	6 : 18	6 :36	18	0 :55	2 :47	65.8	55	167	112	71.8	75.9	181.7
17	11	6291	6 : 31	6 :39	8	0 :56	2 :52	68.4	56	172	116	73.3	78.0	183.1
17	12	8859	6 : 37	6 :41	4	3 :10	3 :36	130.5	190	216	26	41.2	126.4	218.0
17	13	8865	6 : 33	6 :45	12	2 : 6	4 :20	148.0	126	260	134	70.5	140.0	227.8
17	14	7750	6 : 35	6 :50	15	2 : 3	2 :56	135.6	123	176	53	66.1	130.4	220.9
17	15	8644	6 : 35	6 :53	18	1 :38	4 : 6	114.6	98	246	148	70.2	114.0	209.1
17	16	7753	6 : 47	6 :57	10	1 :30	2 : 1	99.2	90	121	31	66.1	102.0	200.4
17	17	7345	6 : 49	7 : 0	11	1 :11	2 : 9	77.5	71	129	58	65.5	85.1	188.2
17	18	8857	6 : 53	7 : 2	9	1 :38	2 : 6	116.9	98	126	28	71.6	115.8	210.4
17	19	8103	6 : 56	7 : 4	8	1 :56	2 :22	137.9	116	142	26	71.3	132.2	222.2
17	20	7759	6 : 59	7 : 6	7	1 :10	2 :47	80.2	70	167	97	68.7	87.2	189.7
17	21	8782	7 : 1	7 : 9	8	2 : 0	2 :26	143.2	120	146	26	71.6	136.3	225.1
17	22	7758	7 : 1	7 :11	10	1 :25	3 : 2	92.5	85	182	97	65.3	96.8	196.7
17	23	8531	7 : 7	7 :15	8	2 : 3	2 :29	142.8	123	149	26	69.7	136.0	224.9
17	24	8646	7 : 7	7 :17	10	1 :13	2 : 2	83.1	73	122	49	68.3	89.4	191.4
17	25	8650	7 : 4	7 :19	15	2 :13	2 :32	155.4	133	152	19	70.1	145.8	232.0
17	26	7348	7 : 10	7 :22	12	1 :13	2 : 8	75.2	73	128	55	61.8	83.3	186.9
17	27	8854	7 : 11	7 :24	13	1 : 5	2 :14	71.4	65	134	69	65.9	80.3	184.8
17	28	7356	7 : 18	7 :26	8	1 :10	2 :51	77.2	70	171	101	66.2	84.8	188.1
17	29	7347	7 : 22	7 :29	7	1 :24	2 : 2	87.8	84	122	38	62.7	93.1	194.0
17	30	7749	7 : 23	7 :31	8	1 :24	3 : 1	73.0	84	181	97	52.1	81.5	185.7
17	31	8864	7 : 25	7 :34	9	2 :40	3 :34	147.8	160	214	54	55.4	139.9	227.7
17	32	7755	7 : 25	7 :38	13	2 :33	3 :21	118.2	153	201	48	46.4	116.8	211.1
17	33	8785	7 : 29	7 :41	12	2 :19	3 :14	127.7	139	194	55	55.1	124.2	216.4
17	34	8535	7 : 30	7 :45	15	0 :22	2 :20	25.9	22	140	118	70.6	44.8	159.2
17	35	7961	7 : 32	7 :47	15	1 :41	2 :21	109.9	101	141	40	65.3	110.3	206.4
17	36	7196	7 : 11	7 :49	38	2 : 0	3 :31	79.6	120	211	91	39.8	86.7	189.4
17	37	7760	6 : 43	7 :53	70	1 :24	1 :57	86.7	84	117	33	61.9	92.2	193.4
17	38	7745	7 : 49	7 :55	6	2 : 8	2 :35	134.7	128	155	27	63.1	129.7	220.4
17	39	7746	7 : 50	7 :57	7	1 :16	2 : 9	79.4	76	129	53	62.7	86.5	189.3
17	40	6226	6 : 50	8 : 0	70	0 :54	3 : 2	59.7	54	182	128	66.3	71.2	178.2
17	41	8877	6 : 38	8 : 3	85	2 :22	2 :45	163.8	142	165	23	69.2	152.4	236.7
17	42	8102	8 : 0	8 : 6	6	1 :33	3 : 7	104.9	93	187	94	67.7	106.4	203.6
17	43	8871	6 : 54	8 : 9	75	2 : 1	3 :11	141.5	121	191	70	70.2	135.0	224.2
17	44	8112	7 : 4	8 :12	68	1 :14	2 :10	86.3	74	130	56	70.0	91.9	193.2
17	45	7353	7 : 29	8 :14	45	1 :30	2 : 2	95.5	90	122	32	63.7	99.1	198.3
17	46	8647	6 : 44	8 :16	92	1 :44	3 :33	111.0	104	213	109	64.0	111.2	207.0
17	47	7346	6 : 52	8 :20	88	1 :31	3 :38	77.4	91	218	127	51.0	85.0	188.2
17	48	7747	6 : 10	8 :23	133	1 :25	3 :34	92.8	85	214	129	65.5	97.0	196.8
17	49	7757	6 : 32	8 :27	115	1 :25	2 :36	94.0	85	156	71	66.4	97.9	197.5
17	50	7756	6 : 33	8 :29	116	1 : 9	3 :39	75.0	69	219	150	65.2	83.1	186.8
17	51	7754	6 : 43	8 :33	110	1 :46	3 : 0	111.8	106	180	74	63.3	111.8	207.5
17	52	7351	6 : 37	8 :36	119	1 :42	2 :40	82.6	102	160	58	48.6	89.0	191.1
17	53	8113	6 : 6	8 :39	153	1 :26	2 :56	44.0	86	176	90	30.7	58.9	169.4
17	54	6225	8 : 40	12 :10	210	2 :53	8 : 2	201.1	173	482	309	69.7	181.4	257.7

FUELLING TIME

Regression Output:

Constant	24.61314
Std Err of Y Est	28.86830
R Squared	0.66607
No. of Observations	284.000
Degrees of Freedom	282.000
X Coefficien	0.77989
Std Err of C	0.03288

Regression Output:

Constant	144.698
Std Err of Y Est	60.71919
R Squared	0.18956
No. of Observations	284.000
Degrees of Freedom	282.000
X Coefficien	0.56172
Std Err of C	0.06916

DATE	ARR #	BUS #	QUEUE ARRIVAL H : M	FUEL ARRIVAL H : M	QUEUE TIME	----TIME----- FUEL ONLY MIN:S	TOTAL CYCLE MIN:S	FUEL AMOUNT (L)	FUEL TIME (SEC)	TOTL TIME (SEC)	DWELL TIME (SEC)	AVG FUEL DELV RT (L/MIN)	REGR LINE FUEL TIME	REGR LINE TOTAL TIME
17	55	8529	9 : 3	12 :18	195	2 :30	5 :14	142.1	150	314	164	56.8	135.4	224.5
17	56	8101	11 : 0	12 :23	83	0 :30	2 :57	44.4	30	177	147	88.8	59.2	169.6
17	57	8641	12 : 26	12 :27	1	1 :53	5 : 7	134.9	113	307	194	71.6	129.8	220.5
17	58	8781	:	12 :32	-	2 :23	4 :48	166.3	143	288	145	69.8	154.3	238.1
17	59	8648	12 : 35	12 :37	2	1 :52	3 :46	141.5	112	226	114	75.8	135.0	224.2
17	60	8645	12 : 42	12 :44	2	2 :25	5 : 5	170.7	145	305	160	70.6	157.7	240.6
17	61	8856	12 : 46	12 :49	3	2 :20	5 :10	179.1	140	310	170	76.8	164.3	245.3
17	62	8872	12 : 57	12 :58	1	2 :54	3 :34	179.9	174	214	40	62.0	164.9	245.8
17	63	8581	:	1 : 3	-	1 : 1	2 :45	54.4	61	165	104	53.5	67.0	175.3
17	64	8533	1 : 9	1 :13	4	3 : 4	4 :30	205.8	184	270	86	67.1	185.1	260.3
17	65	8870	1 : 19	1 :22	3	2 :53	4 : 9	187.1	173	249	76	64.9	170.5	249.8
17	66	8867	1 : 20	1 :27	7	2 :43	3 :40	183.9	163	220	57	67.7	168.0	248.0
17	67	6290	1 : 21	1 :30	9	2 :26	3 :50	177.7	146	230	84	73.0	163.2	244.5
17	68	8863	1 : 21	1 :34	13	3 : 4	3 :34	215.4	184	214	30	70.2	192.6	265.7
17	69	8876	1 : 27	1 :38	11	2 :58	3 :49	206.2	178	229	51	69.5	185.4	260.5
17	70	8640	1 : 28	1 :42	14	3 :42	4 :32	257.1	222	272	50	69.5	225.1	289.1
17	71	8114	1 : 34	1 ;46	12	2 :11	3 :52	148.2	131	232	101	67.9	140.2	227.9
17	72	8869	1 : 40	1 :50	10	2 :53	3 :22	198.7	173	202	29	68.9	179.6	256.3
17	73	8113	1 : 55	1 :55	0	1 :38	2 :30	79.8	98	150	52	48.9	86.8	189.5
17	74	8782	1 : 45	1 :56	11	0 :58	2 : 9	63.6	58	129	71	65.8	74.2	180.4
17	75	6291	1 : 49	1 :58	9	1 :24	2 :50	96.2	84	170	86	68.7	99.6	198.7
17	76	8861	1 : 55	2 : 0	5	2 :22	2 :59	166.4	142	179	37	70.3	154.4	238.2
17	77	6229	1 : 45	2 : 3	18	2 : 1	4 :10	75.0	121	250	129	37.2	83.1	186.8
17	78	7751	2 : 5	2 : 7	2	3 :53	4 :30	254.7	233	270	37	65.6	223.3	287.8
17	79	8862	2 : 7	2 :12	5	0 :56	2 :47	61.9	56	167	111	66.3	72.9	179.5
17	80	6227	2 : 7	2 :14	7	3 :29	4 :19	242.3	209	259	50	69.6	213.6	280.8
17	81	8784	2 : 10	2 :19	9	2 : 7	5 :20	154.3	127	320	193	72.9	145.0	231.4
17	82	6228	2 : 11	2 :25	14	1 :24	2 :42	88.7	84	162	78	63.4	93.8	194.5
17	83	8873	2 : 12	2 :28	16	1 :41	3 :29	48.0	101	209	108	28.5	62.0	171.7
17	84	8527	2 : 16	2 :31	15	2 :37	3 :23	179.4	157	203	46	68.6	164.5	245.5
17	85	7355	2 : 14	2 :34	20	1 :57	3 :36	127.4	117	216	99	65.3	124.0	216.3
17	86	6292	2 : 17	2 :38	21	1 :51	3 :21	130.5	111	201	90	70.5	126.4	218.0
17	87	8532	2 : 28	2 :42	14	0 :54	2 :25	55.9	54	145	91	62.1	68.2	176.1
17	88	6293	2 : 17	2 :45	28	1 : 9	2 :55	78.7	69	175	106	68.4	86.0	188.9
17	89	8879	2 : 31	2 :47	16	2 :11	4 :22	151.7	131	262	131	69.5	142.9	229.9
17	90	8115	2 : 18	2 :52	34	2 :31	3 :50	165.1	151	230	79	65.6	153.4	237.4
17	91	8642	2 : 19	2 :56	37	3 :12	4 :52	238.9	192	292	100	74.7	210.9	278.9
17	92	8783	2 : 45	3 : 1	16	3 :31	4 :30	345.5	211	270	59	98.2	294.1	338.8
17	93	8859	3 : 6	3 : 8	2	1 : 1	2 :42	60.1	61	162	101	59.1	71.5	178.5
17	94	8649	3 : 13	3 :14	1	2 :34	3 :47	171.0	154	227	73	66.6	158.0	240.8
18	1	7349	:	6 : 9	-	0 :41	3 :26	65.4	41	206	165	95.7	75.6	181.4
18	2	8865	5 : 30	6 :12	42	2 :12	3 :11	96.2	132	191	59	43.7	99.6	198.7
18	3	8532	5 : 41	6 :15	34	1 :40	4 :19	85.3	100	259	159	51.2	91.1	192.6
18	4	8878	6 : 14	6 :19	5	2 :50	4 :16	226.1	170	256	86	79.8	200.9	271.7
18	5	8782	5 : 59	6 :24	25	2 :29	3 :46	126.5	149	226	77	50.9	123.3	215.8
18	6	8116	5 : 59	6 :28	29	1 :40	2 :25	85.1	100	145	45	51.1	91.0	192.5
18	7	8640	6 : 22	6 :30	8	0 :56	2 :23	41.7	56	143	87	44.7	57.1	168.1
18	8	8644	6 : 13	6 :32	19	1 : 5	3 :10	45.7	65	190	125	42.2	60.3	170.4
18	9	8101	6 : 26	6 :36	10	2 :21	3 :32	93.6	141	212	71	39.8	97.6	197.3
18	10	8867	6 : 28	6 :39	11	0 :50	4 :39	37.1	50	279	229	44.5	53.5	165.5
18	11	8860	6 : 34	6 :44	10	1 :57	3 :23	81.3	117	203	86	41.7	88.0	190.4
18	12	7346	6 : 35	6 :47	12	1 :13	4 : 0	71.2	73	240	167	58.5	80.1	184.7
18	13	8861	6 : 42	6 :51	9	3 : 9	4 :26	124.6	189	266	77	39.6	121.8	214.7
18	14	6292	6 : 36	6 :56	20	3 :10	4 :30	132.3	190	270	80	41.8	127.8	219.0
18	15	7348	6 : 37	7 : 1	24	2 : 9	3 :46	231.3	129	226	97	107.6	205.0	274.6

DATE	ARR #	BUS #	QUEUE ARRIVAL H : M	FUEL ARRIVAL H : M	QUEUE TIME	----TIME----- FUEL ONLY MIN:S	TOTAL CYCLE MIN:S	FUEL AMOUNT (L)	FUEL TIME (SEC)	TOTL TIME (SEC)	DWELL TIME (SEC)	AVG FUEL DELV RT (L/MIN)	REGR LINE FUEL TIME	REGR LINE TOTAL TIME
18	16	8784	6 : 47	7 : 4	17	1 :16	3 :35	35.3	76	215	139	27.9	52.1	164.5
18	17	8868	6 : 48	7 : 8	20	2 : 9	3 :41	87.6	129	221	92	40.7	92.9	193.9
18	18	8876	6 : 53	7 :12	19	2 :32	3 :25	103.8	152	205	53	41.0	105.6	203.0
18	19	7752	6 : 56	7 :15	19	3 : 3	4 :23	135.6	183	263	80	44.5	130.4	220.9
18	20	8102	7 : 0	7 :20	20	2 :34	3 :35	104.0	154	215	61	40.5	105.7	203.1
18	21	7351	7 : 3	7 :23	20	1 :20	3 :51	67.3	80	231	151	50.5	77.1	182.5
18	22	7758	7 : 12	7 :27	15	3 :31	4 :31	151.5	211	271	60	43.1	142.8	229.8
18	23	8529	7 : 7	7 :32	25	1 :28	2 :53	62.2	88	173	85	42.4	73.1	179.6
18	24	8533	:	7 :35	-	1 :45	2 :55	69.8	105	175	70	39.9	79.0	183.9
18	25	8872	7 : 18	7 :37	19	1 :34	3 :33	90.5	94	213	119	57.8	95.2	195.5
18	26	8856	7 : 19	7 :41	22	1 :57	3 :19	85.2	117	199	82	43.7	91.1	192.6
18	27	7749	7 : 21	7 :45	24	1 :49	3 : 6	84.7	109	186	77	46.6	90.7	192.3
18	28	8617	7 : 26	7 :48	22	3 :20	4 : 0	137.2	200	240	40	41.2	131.6	221.8
18	29	7750	7 : 31	7 :52	21	3 :57	4 :26	168.0	237	266	29	42.5	155.6	239.1
18	30	8535	:	7 :56	-	3 : 3	3 :35	148.4	183	215	32	48.7	140.3	228.1
18	31	8781	6 : 57	8 : 0	63	2 :27	3 : 3	120.8	147	183	36	49.3	118.8	212.6
18	32	8854	6 : 50	8 : 3	73	2 :24	3 :15	120.8	144	195	51	50.3	118.8	212.6
18	33	7746	7 : 24	8 : 6	42	1 :34	2 :16	101.8	94	136	42	65.0	104.0	201.9
18	34	8875	7 : 53	8 : 9	16	0 :25	3 :20	13.9	25	200	175	33.4	35.5	152.5
18	35	8112	6 : 44	8 :12	88	2 :18	3 : 1	111.5	138	181	43	48.5	111.6	207.3
18	36	8642	7 : 23	8 :15	52	1 :54	2 :32	79.6	114	152	38	41.9	86.7	189.4
18	37	7758	:	8 :18	-	1 : 9	2 :54	77.1	69	174	105	67.0	84.7	188.0
18	38	8530	6 : 41	8 :21	100	3 :13	3 :53	152.2	193	233	40	47.3	143.3	230.2
18	39	7760	6 : 38	8 :25	107	2 :25	3 : 5	148.3	145	185	40	61.4	140.3	228.0
18	40	8531	6 : 32	8 :28	116	2 :26	3 :34	112.8	146	214	68	46.4	112.6	208.1
18	41	8879	7 : 12	8 :31	79	1 :15	2 :37	61.5	75	157	82	49.2	72.6	179.2
18	42	7353	7 : 0	8 :34	94	1 :30	2 :10	95.9	90	130	40	63.9	99.4	198.6
18	43	7751	7 : 16	8 :36	80	2 :18	3 :45	146.7	138	225	87	63.8	139.0	227.1
18	44	8117	7 : 59	8 :40	41	3 : 1	3 :43	141.4	181	223	42	46.9	134.9	224.1
18	45	7961	7 : 25	8 :44	79	2 :14	2 :48	112.2	134	168	34	50.2	112.1	207.7
18	46	8874	6 : 30	8 :47	137	2 :34	3 :13	122.2	154	193	39	47.6	119.9	213.3
18	47	8113	6 : 55	8 :50	115	1 :26	2 :49	76.7	86	169	83	53.5	84.4	187.8
18	48	8870	8 : 48	9 :37	49	2 : 5	2 :52	140.5	125	172	47	67.4	134.2	223.6
18	49	7196	6 : 51	9 :41	170	1 :17	1 :54	80.8	77	114	37	63.0	87.6	190.1
18	50	7754	6 : 27	9 :42	195	1 :29	2 : 1	95.0	89	121	32	64.0	98.7	198.1
18	51	8103	:	9 :45	-	1 : 2	2 :33	74.7	62	153	91	72.3	82.9	186.7
18	52	8858	6 : 25	9 :47	202	1 :10	2 :59	76.6	70	179	109	65.7	84.4	187.7
18	53	8877	6 : 52	9 :50	178	2 :23	3 :25	164.1	143	205	62	68.9	152.6	236.9
18	54	8869	6 : 25	9 :54	209	0 :43	2 :37	45.5	43	157	114	63.5	60.1	170.3
18	55	8534	6 : 10	9 :57	227	1 : 1	1 :53	60.6	61	113	52	59.6	71.9	178.7
18	56	8528	6 : 10	9 :59	229	0 :40	2 :27	45.4	40	147	107	68.1	60.0	170.2
18	57	8645	6 : 10	10 : 1	231	0 :42	2 : 0	55.6	42	120	78	79.4	68.0	175.9
18	58	6291	9 : 2	12 :16	194	1 :57	3 :38	140.4	117	218	101	72.0	134.1	223.6
18	59	7354	9 : 10	12 :19	189	2 : 7	3 : 2	135.6	127	182	55	64.1	130.4	220.9
18	60	6229	10 : 10	12 :22	132	0 :19	2 :18	10.1	19	138	119	31.9	32.5	150.4
18	61	8864	9 : 0	12 :24	204	1 :52	4 :11	130.0	112	251	139	69.6	126.0	217.7
18	62	7753	10 : 12	12 :29	137	2 : 1	2 :33	146.6	121	153	32	72.7	138.9	227.0
18	63	8855	11 : 11	12 :31	80	1 :47	2 :43	161.0	107	163	56	90.3	150.2	235.1
18	64	8535	10 : 22	12 :34	132	0 :30	2 :43	144.2	30	163	133	288.4	137.1	225.7
18	65	7345	12 : 28	12 :36	8	4 :57	6 : 5	65.0	297	365	68	13.1	75.3	181.2
18	66	7962	12 : 35	12 :43	8	2 :20	2 :57	158.3	140	177	37	67.8	148.1	233.6
18	67	8650	12 : 29	12 :46	17	2 :57	3 :20	201.9	177	200	23	68.4	182.1	258.1
18	68	7745	12 : 42	12 :49	7	1 :44	2 :58	122.1	104	178	74	70.4	119.8	213.3
18	69	8873	12 : 48	12 :52	4	2 :18	3 : 1	170.1	138	181	43	74.0	157.3	240.2
18	70	8640	12 : 53	12 :55	2	1 : 0	3 :59	36.5	60	239	179	36.5	53.1	165.2

DATE	AER #	BUS #	QUEUE ARRIVAL H : M	FUEL ARRIVAL H : M	QUEUE TIME	TIME FUEL ONLY MIN:S	TIME TOTAL CYCLE MIN:S	FUEL AMOUNT (L)	FUEL TIME (SEC)	TOTL TIME (SEC)	DWELL TIME (SEC)	AVG FUEL DELV RT (L/MIN)	RGER LINE FUEL TIME	RGER LINE TOTAL TIME
18	71	8785	12 : 55	12 :59	4	2 :32	4 :54	176.3	152	294	142	69.6	162.1	243.7
18	72	8783	1 : 11	1 :14	3	3 :13	5 :32	222.1	193	332	139	69.0	197.8	269.5
18	73	8866	1 : 17	1 :20	3	1 :58	3 :38	130.9	118	218	100	66.6	126.7	218.2
18	74	6225	1 : 19	1 :23	4	2 :44	3 :57	189.2	164	237	73	69.2	172.2	251.0
18	75	8863	1 : 19	1 :27	8	2 :37	3 :16	179.2	157	196	39	68.5	164.4	245.4
18	76	8115	1 : 22	1 :31	9	2 :20	3 : 4	173.4	140	184	44	74.3	159.8	242.1
18	77	8641	1 : 23	1 :34	11	2 :16	2 :46	154.8	136	166	30	68.3	145.3	231.7
18	78	7756	1 : 32	1 :37	5	2 :17	3 :40	158.7	137	220	83	69.5	148.4	233.8
18	79	6226	1 : 39	1 :40	1	3 :50	6 :46	264.0	230	406	176	68.9	230.5	293.0
18	80	8857	1 : 43	1 :47	4	3 : 8	3 :32	212.2	188	212	24	67.7	190.1	263.9
18	81	8872	1 : 45	1 :51	6	0 :55	2 :17	61.5	55	137	82	67.1	72.6	179.2
18	82	8532	1 : 48	1 :53	5	0 :58	3 :42	58.9	58	222	164	60.9	70.5	177.8
18	83	8102	1 : 48	1 :56	8	1 : 7	3 : 6	77.4	67	186	119	69.3	85.0	188.2
18	84	8116	1 : 53	1 :59	6	0 :54	5 :20	64.7	54	320	266	71.9	75.1	181.0
18	85	8648	2 : 1	2 : 6	5	2 :17	3 :27	154.5	137	207	70	67.7	145.1	231.5
18	86	7747	2 : 5	2 : 9	4	2 :47	5 :30	187.8	167	330	163	67.5	171.1	250.2
18	87	8871	2 : 5	2 :14	9	3 :41	3 :57	247.5	221	237	16	67.2	217.6	283.7
18	88	8100	2 : 7	2 :18	11	2 :21	3 :23	167.9	141	203	62	71.4	155.6	239.0
18	89	6290	2 : 9	2 :22	13	2 : 3	3 : 7	138.1	123	187	64	67.4	132.3	222.3
18	90	8114	2 : 10	2 :25	15	1 : 2	3 :36	83.4	62	216	154	80.7	89.7	191.5
18	91	8878	2 : 13	2 :28	15	1 :17	3 :45	88.9	77	225	148	69.3	93.9	194.6
18	92	8646	2 : 17	2 :32	15	1 :49	2 :45	123.0	109	165	56	67.7	120.5	213.8
18	93	8862	2 : 17	2 :35	18	1 :26	2 :14	97.6	86	134	48	68.1	100.7	199.5
18	94	6228	2 : 28	2 :37	9	1 :15	2 :37	85.9	75	157	82	68.7	91.6	193.0
18	95	8859	2 : 34	2 :40	6	1 : 3	2 :49	78.2	63	169	106	74.5	85.6	188.6
18	96	7759	2 : 35	2 :43	8	2 :12	5 :10	148.8	132	310	178	67.6	140.7	228.3
18	97	6293	2 : 41	2 :48	7	3 :18	6 :33	223.8	198	393	195	67.8	199.2	270.4
18	98	6227	2 : 46	2 :54	8	1 :27	2 :40	100.9	87	160	73	69.6	103.3	201.4
19	1	8103	:	6 : 9	-	3 :34	4 :28	155.8	214	268	54	43.7	146.1	232.2
19	2	8533	6 : 3	6 :13	10	2 :57	4 :21	117.7	177	261	84	39.9	116.4	210.8
19	3	6291	5 : 50	6 :17	27	2 :30	3 :13	100.4	150	193	43	40.2	102.9	201.1
19	4	8861	6 : 13	6 :21	8	1 :29	3 : 5	62.7	89	185	96	42.3	73.5	179.9
19	5	6228	6 : 13	6 :24	11	1 :49	2 :58	73.1	109	178	69	40.2	81.6	185.8
19	6	8649	:	6 :27	-	1 :35	3 :15	70.6	95	195	100	44.6	79.7	184.4
19	7	6226	5 : 50	6 :30	40	3 :24	4 :28	136.2	204	268	64	40.1	130.8	221.2
19	8	8867	5 : 50	6 :35	45	3 :24	3 :43	121.0	204	223	19	35.6	119.0	212.7
19	9	6229	6 : 34	6 :38	4	1 :29	2 :43	62.1	89	163	74	41.9	73.0	179.6
19	10	8781	6 : 17	6 :41	24	1 :41	2 :30	70.5	101	150	49	41.9	79.6	184.3
19	11	8785	6 : 19	6 :44	25	1 :13	4 :22	50.5	73	262	189	41.5	64.0	173.1
19	12	8866	6 : 35	6 :48	13	4 :49	6 :47	189.5	289	407	118	39.3	172.4	251.1
19	13	8854	6 : 37	6 :55	18	2 :36	2 :58	105.4	156	178	22	40.5	106.8	203.9
19	14	6292	6 : 47	6 :58	11	2 :51	3 :23	114.6	171	203	32	40.2	114.0	209.1
19	15	7758	6 : 36	7 : 1	25	3 :17	4 : 0	141.0	197	240	43	42.9	134.6	223.9
19	16	7749	6 : 39	7 : 5	26	1 :55	2 :27	84.9	115	147	32	44.3	90.8	192.4
19	17	8872	6 : 48	7 : 8	20	2 : 1	9 : 6	79.3	121	546	425	39.3	86.5	189.2
19	18	8856	6 : 55	7 :12	17	2 :40	3 :31	132.5	160	211	51	49.7	127.9	219.1
19	19	8530	7 : 6	7 :15	9	3 : 9	3 :49	157.0	189	229	40	49.8	147.1	232.9
19	20	8113	7 : 12	7 :19	7	2 :17	3 :14	154.0	137	194	57	67.4	144.7	231.2
19	21	6225	6 : 42	7 :23	41	2 :14	3 :13	158.4	134	193	59	70.9	148.1	233.7
19	22	7355	6 : 48	7 :26	38	1 :23	2 :47	98.4	83	167	84	71.1	101.4	200.0
19	23	8864	7 : 24	7 :29	5	1 :17	2 :30	99.5	77	150	73	77.5	102.2	200.6
19	24	7353	6 : 25	7 :31	66	:50	2 :51	67.9	50	171	121	81.5	77.6	182.8
19	25	8644	6 : 10	7 :34	84	:56	3 :22	57.4	56	202	146	61.5	69.4	176.9
19	26	8102	6 : 38	7 :38	60	1 :51	3 : 6	125.5	111	186	75	67.8	122.5	215.2
19	27	7349	7 : 9	7 :41	32	:57	2 :43	62.6	57	163	106	65.9	73.4	179.9

DATE	ARR #	BUS #	QUEUE ARRIVAL H : M	FUEL ARRIVAL H : M	QUEUE TIME	----TIME----- FUEL ONLY MIN:S	TOTAL CYCLE MIN:S	FUEL AMOUNT (L)	FUEL TIME (SEC)	TOTL TIME (SEC)	DWELL TIME (SEC)	AVG FUEL DELV RT (L/MIN)	REGR LINE FUEL TIME	REGR LINE TOTAL TIME
19	28	8642	7 : 26	7 :43	17	1 :53	2 :38	129.9	113	158	45	69.0	125.9	217.7
19	29	7352	7 : 29	7 :46	17	1 :58	2 :39	136.1	118	159	41	69.2	130.8	221.1
19	30	8865	7 : 28	7 :49	21	:49	3 :35	58.2	49	215	166	71.3	70.0	177.4
19	31	8869	7 : 1	7 :52	51	2 : 9	3 :12	146.3	129	192	63	68.0	138.7	226.9
19	32	8874	7 : 17	7 :56	39	1 :59	2 :53	137.7	119	173	54	69.4	132.0	222.0
19	33	8527	7 : 15	7 :59	44	1 : 3	4 : 9	92.3	63	249	186	87.9	96.6	196.5
19	34	8876	7 : 14	8 : 3	49	1 : 6	2 :38	57.4	66	158	92	52.2	69.4	176.9
19	35	8782	7 : 51	8 : 5	14	:46	2 :53	37.4	46	173	127	48.8	53.8	165.7
19	36	7756	6 : 59	8 : 8	69	1 :31	2 :35	123.3	91	155	64	81.3	120.8	214.0
19	37	8528	7 : 8	8 :11	63	2 : 8	2 :34	145.8	128	154	26	68.3	138.3	226.6
19	38	8646	7 : 11	8 :13	62	2 :35	3 :55	172.8	155	235	80	66.9	159.4	241.8
19	39	7962	7 : 5	8 :17	72	:56	2 :13	61.6	56	133	77	66.0	72.7	179.3
19	40	7755	7 : 57	8 :19	22	3 : 5	3 :40	197.1	185	220	35	63.9	178.3	255.4
19	41	8877	7 : 26	8 :23	57	1 :22	3 :18	92.9	82	198	116	68.0	97.1	196.9
19	42	8648	6 : 23	8 :27	124	1 :11	2 :50	75.4	71	170	99	63.7	83.4	187.1
19	43	7354	6 : 54	8 :29	95	:51	2 :44	57.6	51	164	113	67.8	69.5	177.1
19	44	8859	6 : 58	8 :32	94	1 :10	3 :18	80.9	70	198	128	69.3	87.7	190.1
19	45	8784	7 : 22	8 :35	73	:50	2 :53	48.4	50	173	123	58.1	62.4	171.9
19	46	7760	7 : 17	8 :38	81	2 :19	3 : 0	105.2	139	180	41	45.4	106.7	203.8
19	47	7751	6 : 43	8 :41	118	2 : 7	3 :46	90.1	127	226	99	42.6	94.9	195.3
19	48	6290	:	8 :45	-	3 :27	3 :52	170.8	207	232	25	49.5	157.8	240.6
19	49	8862	5 : 52	8 :49	177	1 :28	2 :39	74.0	88	159	71	50.5	82.3	186.3
19	50	8115	5 : 53	8 :52	179	1 :25	2 :40	72.3	85	160	75	51.0	81.0	185.3
19	51	8532	8 : 45	11 :41	176	1 :47	8 :10	114.4	107	490	383	64.1	113.8	209.0
19	52	8863	9 : 2	11 :50	168	2 : 9	4 : 9	138.6	129	249	120	64.5	132.7	222.6
19	53	6135	:	11 :54	-	2 :42	5 :10	121.9	162	310	148	45.1	119.7	213.2
19	54	8857	11 : 57	11 :59	2	0 :38	6 :30	40.8	38	390	352	64.4	56.4	167.6
19	55	7746	11 : 14	12 : 5	51	1 :41	5 :28	101.5	101	328	227	60.3	103.8	201.7
19	56	8641	11 : 21	12 :10	49	0 :50	3 :11	57.7	50	191	141	69.2	69.6	177.1
19	57	7745	11 : 28	12 :13	45	1 :38	3 :51	96.8	98	231	133	59.3	100.1	199.1
19	58	8870	11 : 28	12 :17	49	1 :14	3 :36	81.4	74	216	142	66.0	88.1	190.4
19	59	8871	11 : 54	12 :21	27	0 :50	3 :34	35.9	50	214	164	43.1	52.6	164.9
19	60	8540	11 : 36	12 :24	48	1 : 9	4 : 9	84.2	69	249	180	73.2	90.3	192.0
19	61	7753	12 : 7	12 :29	22	2 :23	5 :32	134.8	143	332	189	56.6	129.7	220.4
19	62	8531	12 : 30	12 :34	4	2 :18	5 :44	161.7	138	344	206	70.3	150.7	235.5
19	63	7356	12 : 37	12 :40	3	2 :13	4 :34	147.6	133	274	141	66.6	139.7	227.6
19	64	8873	12 : 43	12 :44	1	1 :44	4 :20	121.3	104	260	156	70.0	119.2	212.8
19	65	7750	12 : 51	12 :54	3	1 : 2	2 :45	83.2	62	165	103	80.5	89.5	191.4
19	66	8875	12 : 56	12 :57	1	2 :26	7 :57	174.0	146	477	331	71.5	160.3	242.4
19	67	8860	1 : 1	1 : 5	4	2 :13	4 :30	155.2	133	270	137	70.0	145.7	231.9
19	68	8850	:	1 :15	-	2 :12	4 :16	155.0	132	256	124	70.5	145.5	231.8
19	69	8117	1 : 21	1 :23	2	2 :31	4 :38	181.1	151	278	127	72.0	165.9	246.4
19	70	7752	1 : 22	1 :28	6	2 :30	3 :48	166.0	150	228	78	66.4	154.1	237.9
19	71	8529	1 : 22	1 :32	10	2 :28	3 :32	182.5	148	212	64	74.0	166.9	247.2
19	72	7757	1 : 23	1 :35	12	2 :20	3 :27	158.9	140	207	67	68.1	148.5	234.0
19	73	7961	1 : 24	1 :38	14	3 :14	3 :34	217.7	194	214	20	67.3	194.4	267.0
19	74	8114	1 : 34	1 :42	8	2 :38	3 :18	184.8	158	198	40	70.2	168.7	248.5
19	75	8647	1 : 34	1 :46	12	2 : 6	2 :49	137.7	126	169	43	65.6	132.0	222.0
19	76	7354	1 : 41	1 :49	8	0 :44	2 :28	46.7	44	148	104	63.7	61.0	170.9
19	77	8534	1 : 42	1 :51	9	2 :42	3 :58	189.4	162	238	76	70.1	172.3	251.1
19	78	8535	1 : 51	1 :55	4	2 : 7	3 : 1	162.6	127	181	54	76.8	151.4	236.0
19	79	8644	1 : 56	1 :58	2	0 :32	3 :46	33.2	32	226	194	62.3	50.5	163.3
19	80	8854	1 : 57	2 : 2	5	1 :10	3 :19	91.5	70	199	129	78.4	96.0	196.1
19	81	7348	1 : 58	2 : 4	6	1 :57	3 : 2	129.6	117	182	65	66.5	125.7	217.5
19	82	7747	2 : 0	2 : 7	7	1 :49	5 : 1	115.5	109	301	192	63.6	114.7	209.6

DATE	ARR #	BUS #	QUEUE ARRIVAL H : M	FUEL ARRIVAL H : M	QUEUE TIME	----TIME----- FUEL ONLY MIN:S	TOTAL CYCLE MIN:S	FUEL AMOUNT (L)	FUEL TIME (SEC)	TOTL TIME (SEC)	DWELL TIME (SEC)	AVG FUEL DELV RT (L/MIN)	REGR LINE FUEL TIME	REGR LINE TOTAL TIME
19	83	6227	2 : 2	2 :12	10	2 : 1	4 :32	161.7	121	272	151	80.2	150.7	235.5
19	84	8527	2 : 7	2 :16	9	1 :17	3 :24	90.1	77	204	127	70.2	94.9	195.3
19	85	8116	2 : 7	2 :20	13	2 :36	3 :48	185.0	156	228	72	71.2	168.9	248.6
19	86	8858	2 : 10	2 :24	14	3 :12	4 : 9	224.6	192	249	57	70.2	199.8	270.9
19	87	8864	2 : 12	2 :28	16	1 : 2	4 : 7	76.1	62	247	185	73.6	84.0	187.4
19	88	7345	2 : 13	2 :32	19	1 :28	3 :43	91.0	88	223	135	62.0	95.6	195.8
19	89	7759	2 : 16	2 :36	20	3 : 5	5 :58	181.5	185	358	173	58.9	166.2	246.7
19	90	6293	2 : 25	2 :42	17	3 :29	4 :47	254.2	209	287	78	73.0	222.9	287.5
19	91	8100	2 : 26	2 :46	20	3 : 2	5 :50	211.7	182	350	168	69.8	189.7	263.6
19	92	8533	2 : 36	2 :52	16	1 :29	2 :28	75.3	89	148	59	50.8	83.3	187.0
19	93	8101	2 : 38	2 :55	17	0 :55	2 :35	62.6	55	155	100	68.3	73.4	179.9

AUGUST 31, 1988 AVERAGES 118.3 L 116.5 S 210.9 S 94.3 S 60.9 L/min

Table 3/ TTC Lansdowne Buffer Storage Analysis

INITIAL BUFFER PRESSURE	3,600	PSIG
VEHICLE TANK VOLUME	14,127	SCF
FINAL VEHICLE TANK PRESSURE	3,000	PSIG

INITIAL VEH. TANK PRESS. (PSIG)	TOTAL NG CONSUM. /DAY (SCF)	DIESEL EQUIV. CONSUMP. (L)	FUEL LOAD CONSUM. (%)	REFUEL TIME (MIN)	TOTAL SERV. TIME (MIN)	DWELL TIME (MIN)	BUFFER CAPAC. (SCF)	FINAL* BUFFER PRESS. (PSIG)	BUFFER GAS DELIV. (SCF)	REQ'D NG COMPR. DELIV. (SCF)	AVG. REQ'D COMPR. DELIV. RATE (SCF)	COMPR. RAT'G @3600 PSI (SCFM)	EST'D AVG. DELIV. TO BUFFER (SCFM)	BUFFER FILL TIME (MIN)
0	14,127	314.6	100.0	4.50	5.36	0.86	2,700	578	2,267	11,860	2,636	2,636	2,636	0.860
100	13,656	304.1	96.7	4.36	5.26	0.90	2,888	694	2,331	11,325	2,596	2,596	2,596	0.898
200	13,185	293.6	93.3	4.23	5.16	0.94	3,085	809	2,391	10,794	2,554	2,554	2,554	0.937
300	12,714	283.2	90.0	4.09	5.07	0.97	3,290	923	2,446	10,268	2,510	2,510	2,510	0.975
400	12,243	272.7	86.7	3.95	4.97	1.01	3,505	1,036	2,496	9,747	2,465	2,465	2,465	1.013
500	11,773	262.2	83.3	3.82	4.87	1.05	3,730	1,148	2,541	9,231	2,418	2,418	2,418	1.051
600	11,302	251.7	80.0	3.68	4.77	1.09	3,965	1,257	2,580	8,722	2,369	2,369	2,369	1.089
700	10,831	241.2	76.7	3.55	4.67	1.13	4,210	1,366	2,613	8,218	2,318	2,318	2,318	1.127
800	10,360	230.7	73.3	3.41	4.57	1.17	4,466	1,473	2,639	7,721	2,265	2,265	2,265	1.165
900	9,889	220.2	70.0	3.27	4.48	1.20	4,733	1,578	2,659	7,230	2,209	2,209	2,209	1.204
1000	9,418	209.7	66.7	3.14	4.38	1.24	5,011	1,681	2,671	6,747	2.151	2.151	2.151	1.242
1100	8,947	199.3	63.3	3.00	4.28	1.28	5,298	1,782	2,676	6,271	2,090	2,090	2,090	1.280
1200	8,476	188.8	60.0	2.86	4.18	1.32	5,595	1,881	2,672	5,804	2,027	2,027	2,027	1.318
1300	8,005	178.3	56.7	2.73	4.08	1.36	5,899	1,978	2,659	5,347	1,960	1,960	1,960	1.356
1400	7,534	167.8	53.3	2.59	3.99	1.39	6,210	2,072	2,636	4,898	1,890	1,890	1,890	1.395
1500	7,064	157.3	50.0	2.45	3.89	1.43	6,523	2,163	2,603	4,460	1,817	1,817	1,817	1.433
1600	6,593	146.8	46.7	2.32	3.79	1.47	6,834	2,252	2,559	4,034	1,740	1,740	1,740	1.471
1700	6,122	136.3	43.3	2.18	3.69	1.51	7,138	2,338	2,503	3,619	1,659	1,659	1,659	1.509
1800	5,651	125.8	40.0	2.05	3.59	1.55	7,424	2,420	2,433	3,218	1,573	1,573	1,573	1.547
1900	5,180	115.4	36.7	1.91	3.49	1.59	7,681	2,499	2,350	2,830	1,482	1,482	1,482	1.585
2000	4,709	104.9	33.3	1.77	3.40	1.62	7,894	2,574	2,251	2,458	1,386	1,386	1,386	1.624
2100	4,238	94.4	30.0	1.64	3.30	1.66	8,040	2,644	2,135	2,103	1,285	1,285	1,285	1.662
2200	3,767	83.9	26.7	1.50	3.20	1.70	8,092	2,710	2,001	1,766	1,177	1,177	1,177	1.700
2300	3,296	73.4	23.3	1.36	3.10	1.74	8,015	2,771	1,847	1,450	1,063	1,063	1,063	1.738
2400	2,825	62.9	20.0	1.23	3.00	1.78	7,766	2,826	1,670	1,155	941	941	941	1.776
2500	2,355	52.4	16.7	1.09	2.91	1.81	7,295	2,875	1,470	885	810	810	810	1.814
2600	1,884	41.9	13.3	0.96	2.81	1.85	6,547	2,917	1,243	641	671	671	671	1.852
2700	1,413	31.5	10.0	0.82	2.71	1.89	5,469	2,951	986	427	521	521	521	1.890
2800	942	21.0	6.7	0.68	2.61	1.93	4,021	2,977	696	246	361	361	361	1.928
2900	471	10.5	3.3	0.55	2.51	1.97	2,189	2,994	369	102	187	187	187	1.967
3000	0	0.0	0.0	0.41	2.42	2.01	(0)	3,000	0	(0)	(0)	(0)	(0)	-0.41

* Neglecting compressor input, January 5, 1989

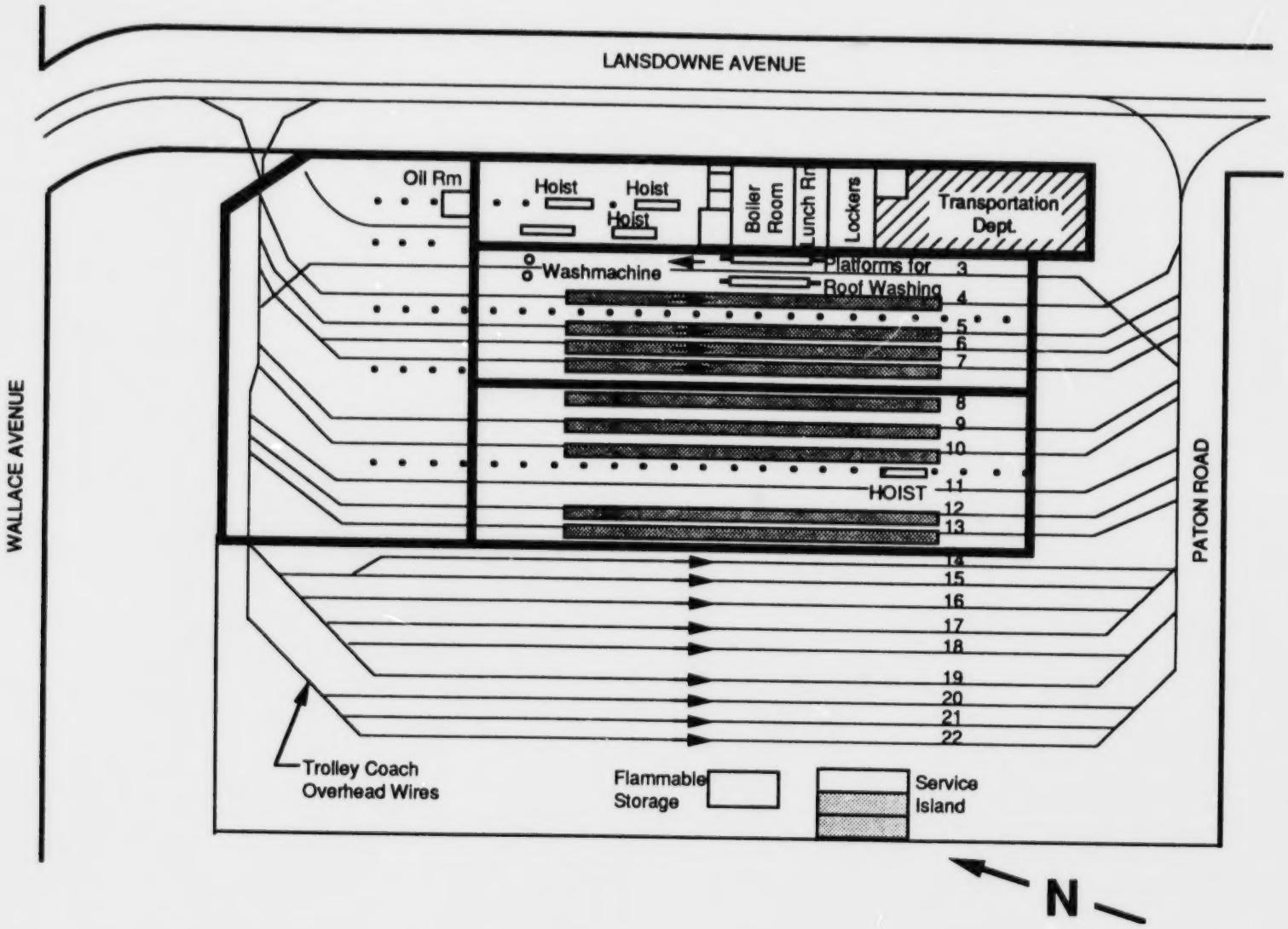

Figure 1/ TTC's Lansdowne Facility

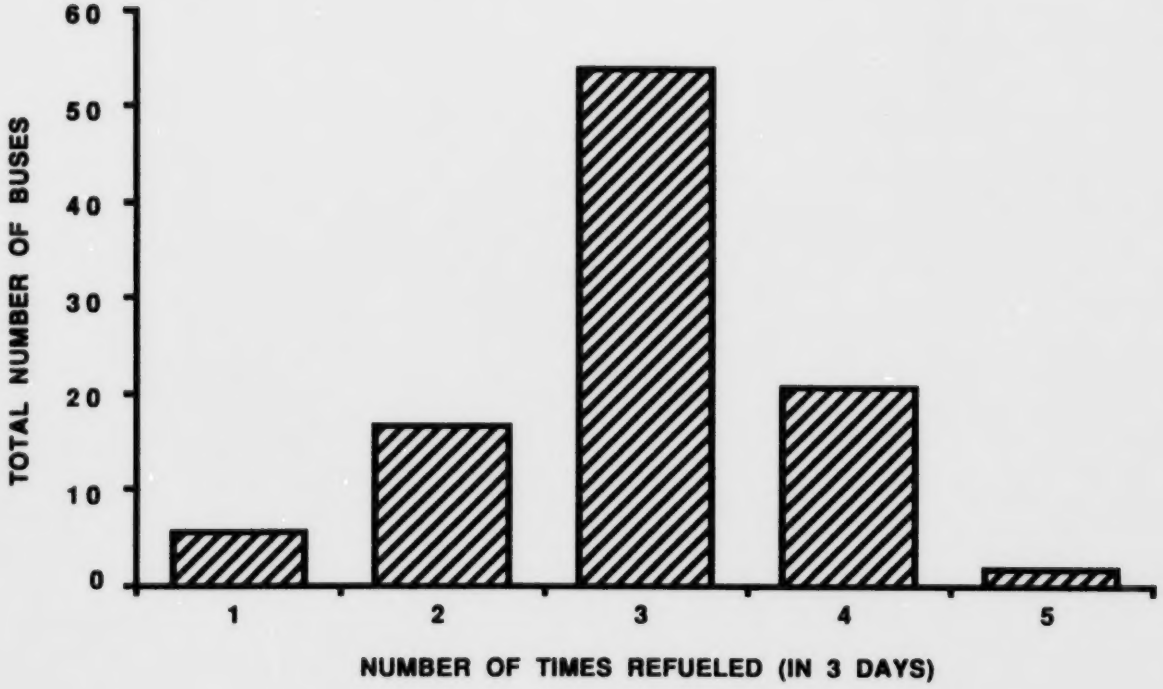

Figure 2/ Refuelling Frequency

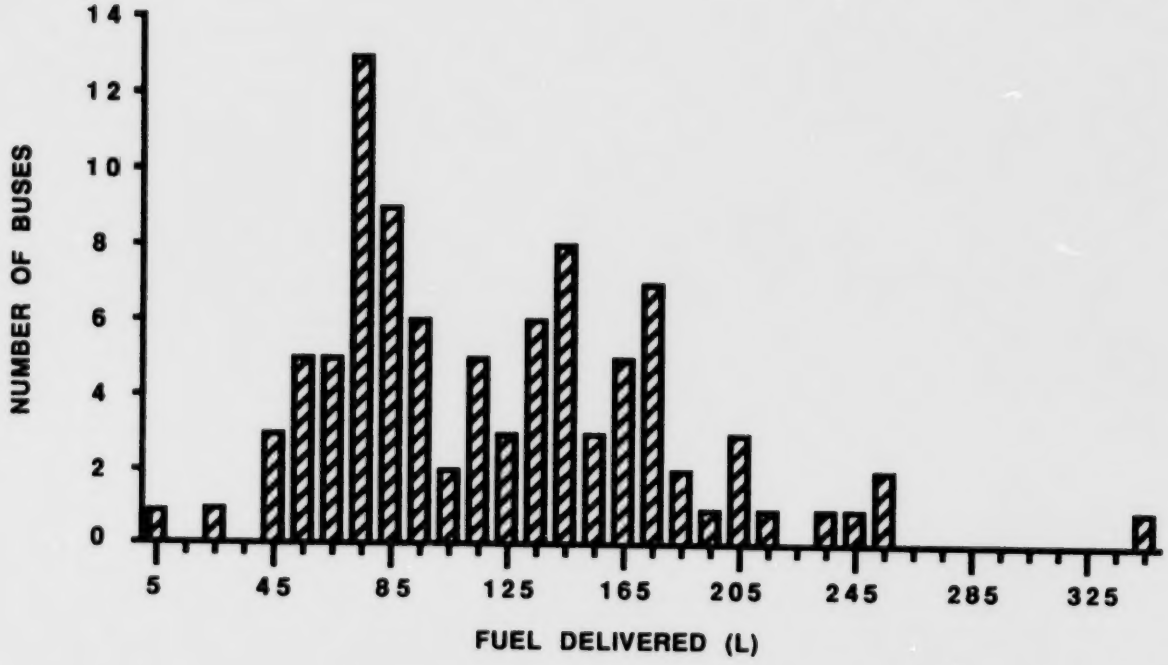

Figure 3a/ Distribution of Fuel Delivered on August 17, 1988

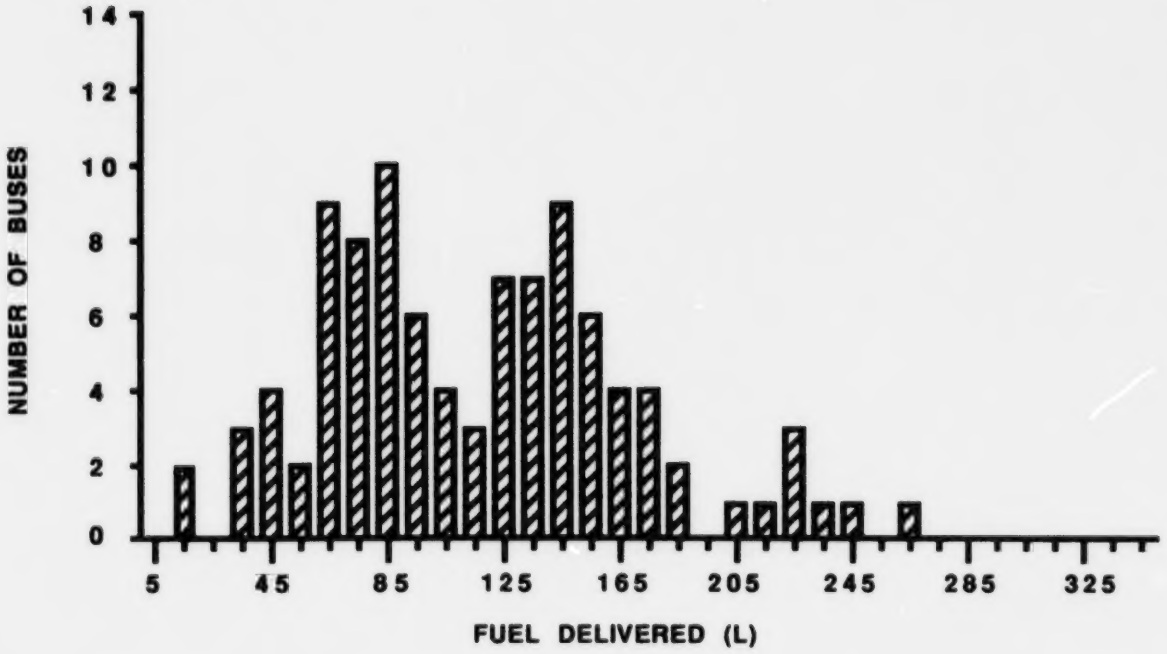

Figure 3b/ Distribution of Fuel Delivered on August 18, 1988

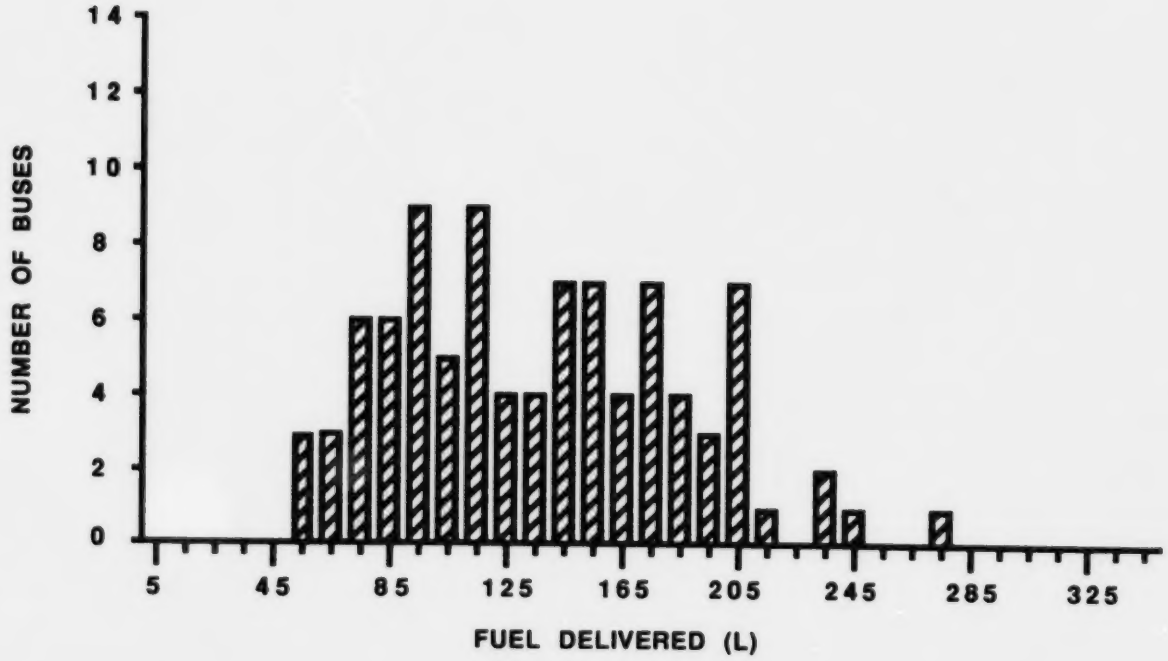

Figure 3c/ Distribution of Fuel Delivered on August 19, 1988

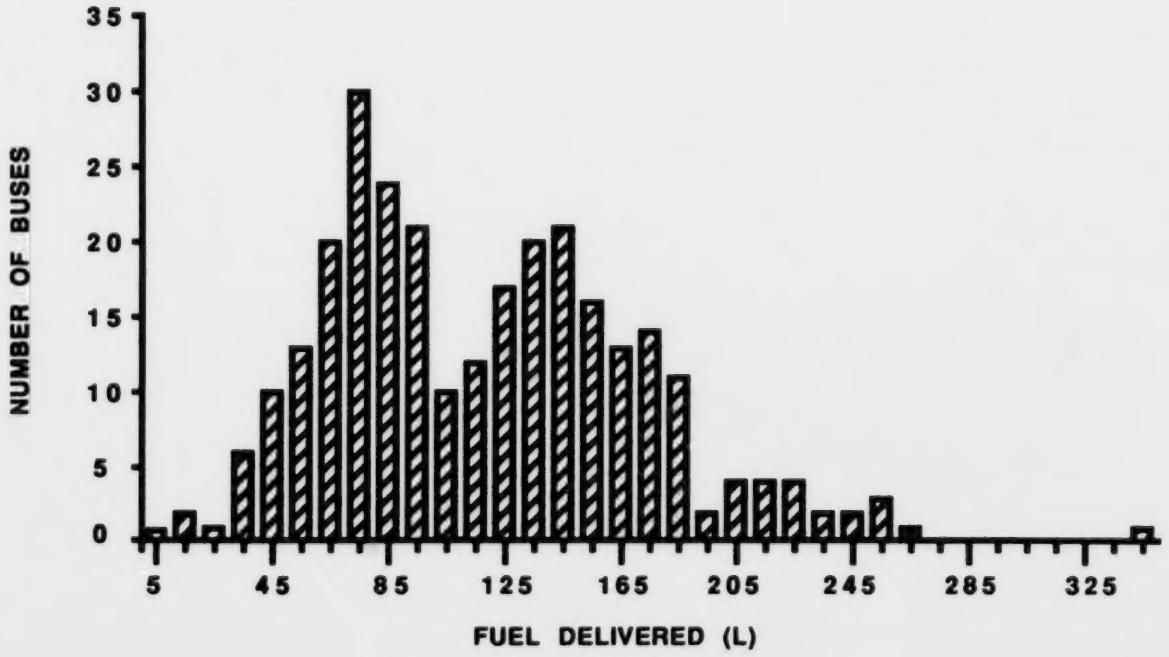

Figure 3d/ Distribution of Fuel Delivered, August 17 to 19, 1988

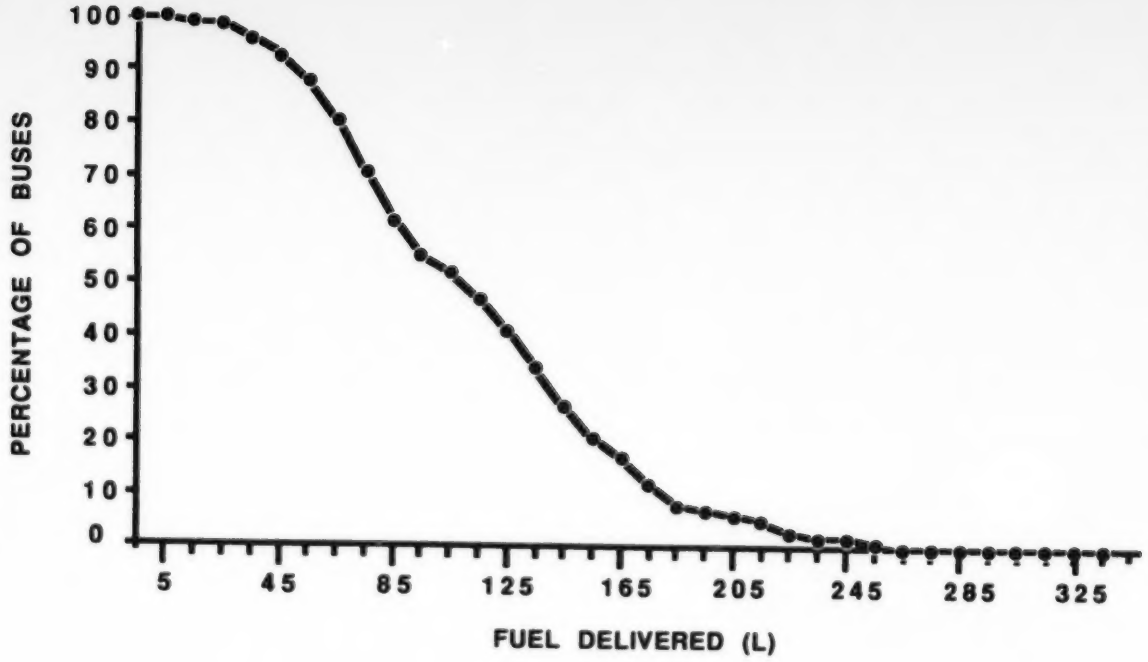

Figure 4/ Cumulative Distribution of Fuel Delivered

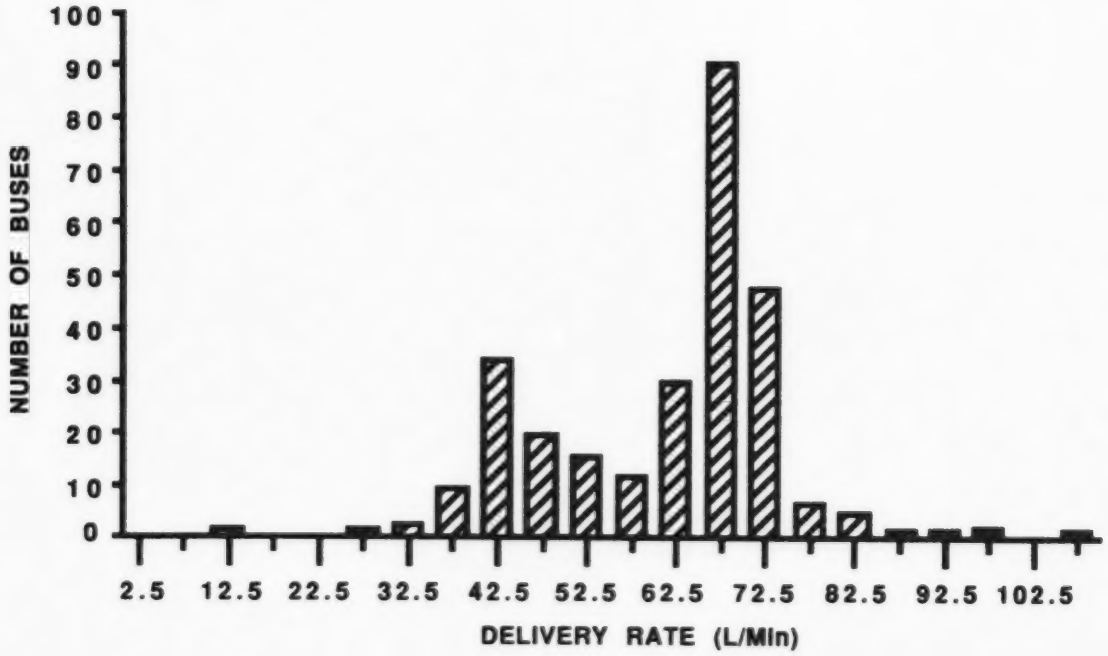

Figure 5/ Distribution of Diesel Pump Delivery Rates, August 17 to 19, 1988

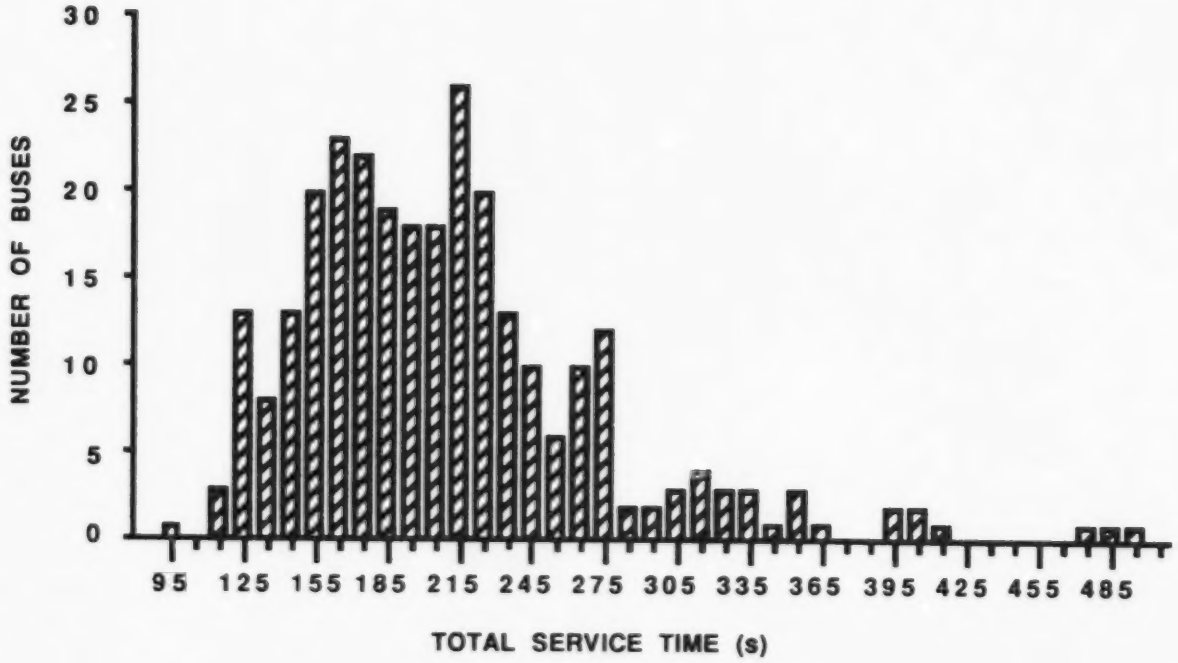

Figure 6/ Distribution of Buses over a Range of Total Service Time

Figure 7/ Cumulative Total Service Time

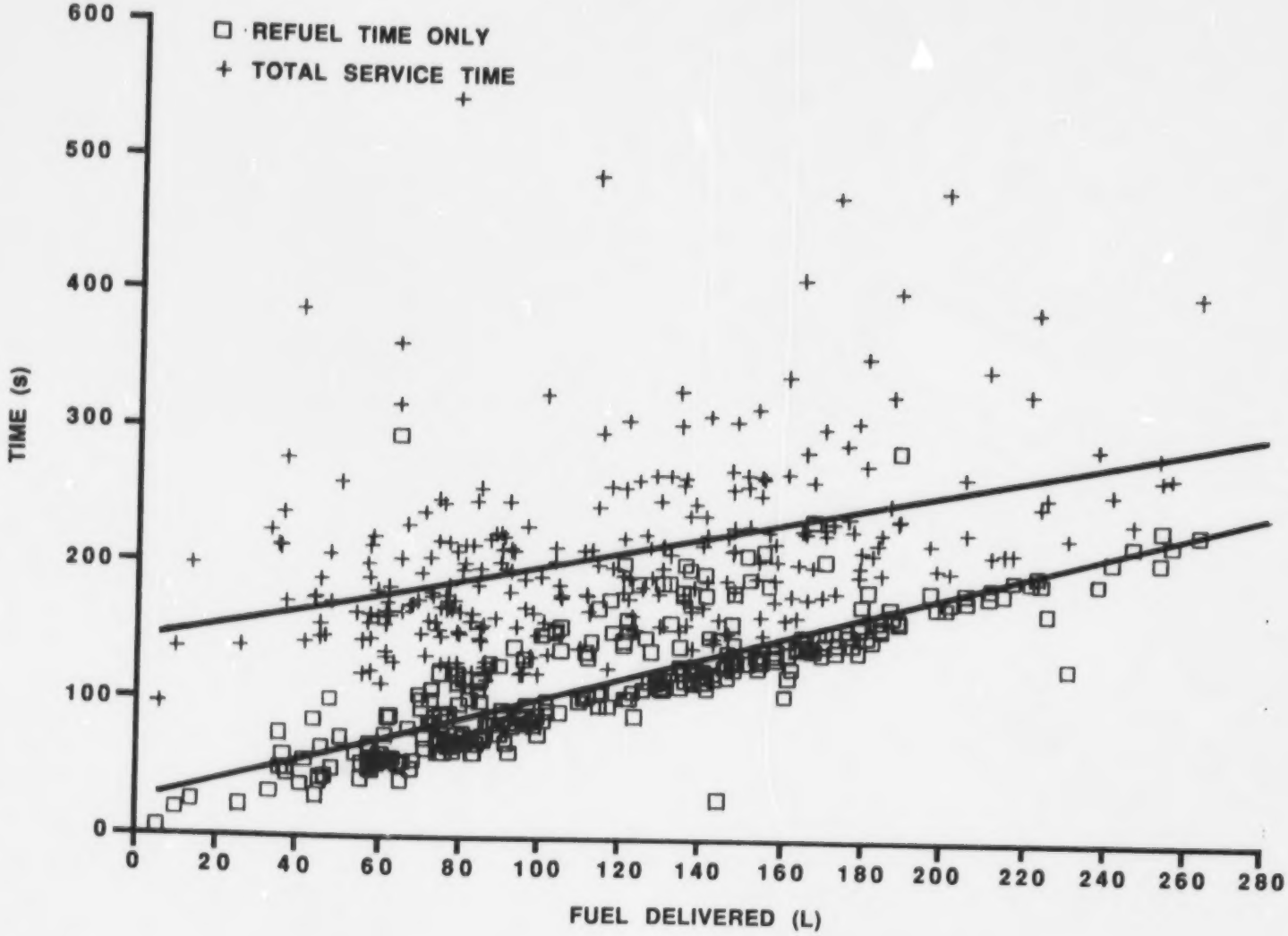

Figure 8/ Regression Analysis of Refuelling Time and Total Service Time

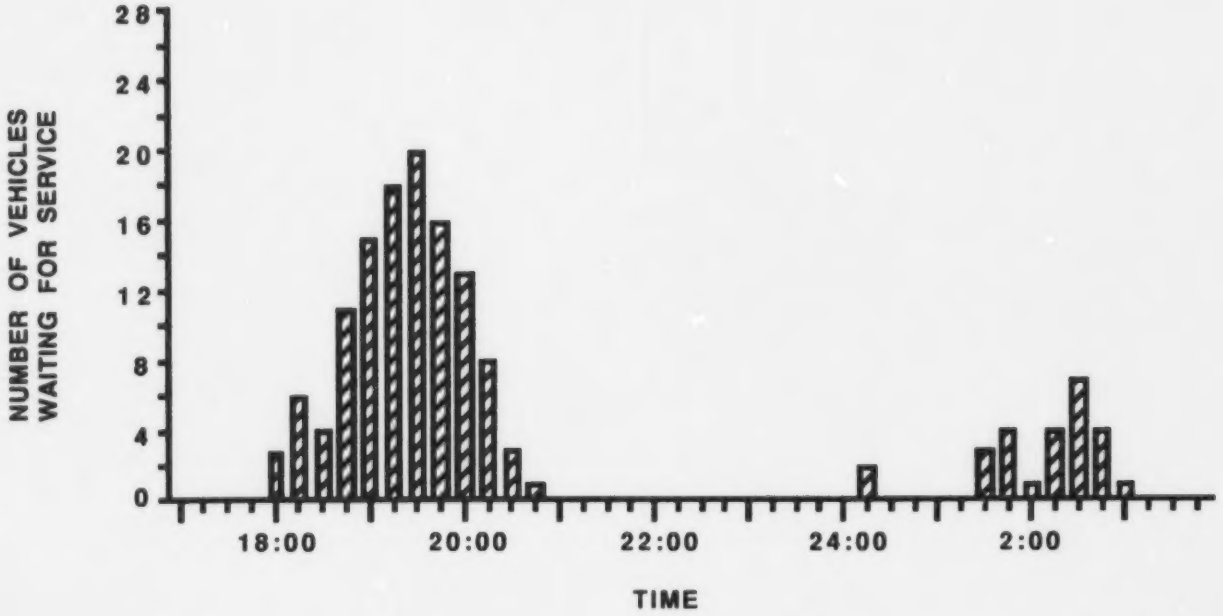

Figure 9a/ Diesel Bus Queuing, August 17, 1988

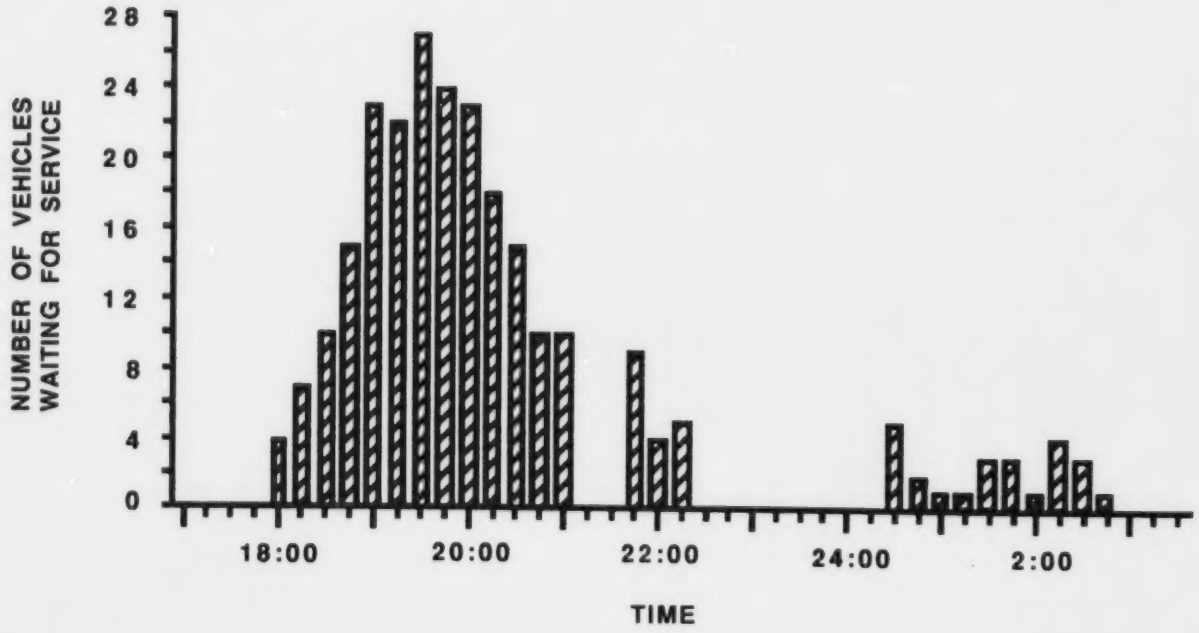

Figure 9b/ Diesel Bus Queuing, August 18, 1988

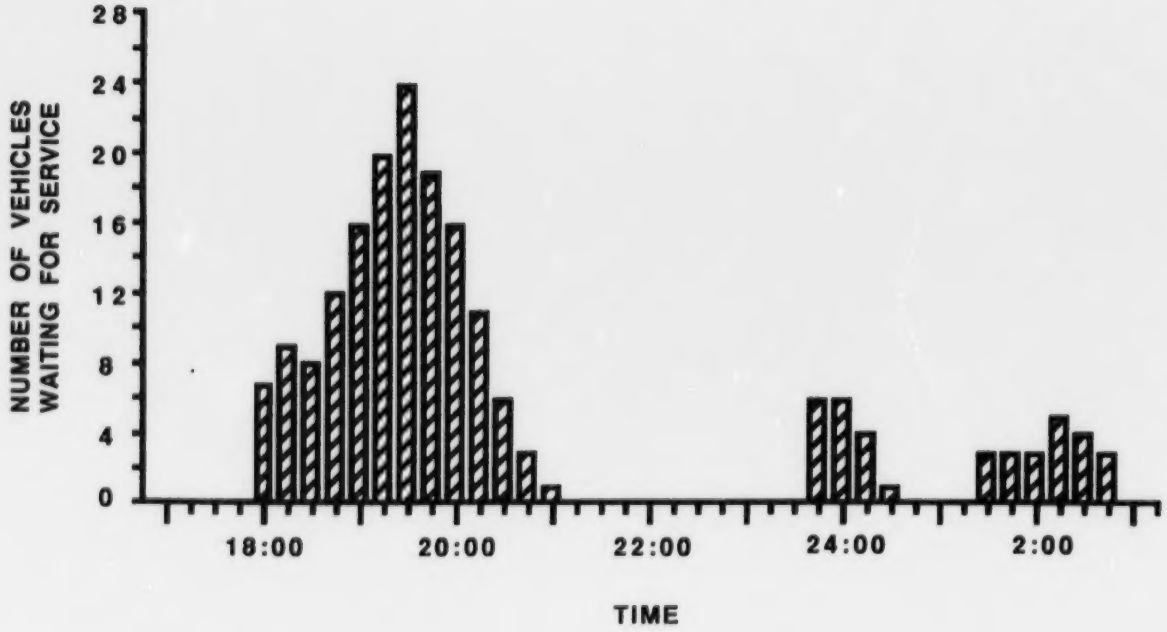

Figure 9c/ Diesel Bus Queuing, August 19, 1988

Figure 10a/ Trolley Bus Arrival at Lansdowne Garage, August 17, 1988

Figure 10b/ Trolley Bus Arrival at Lansdowne Garage, August 18, 1988

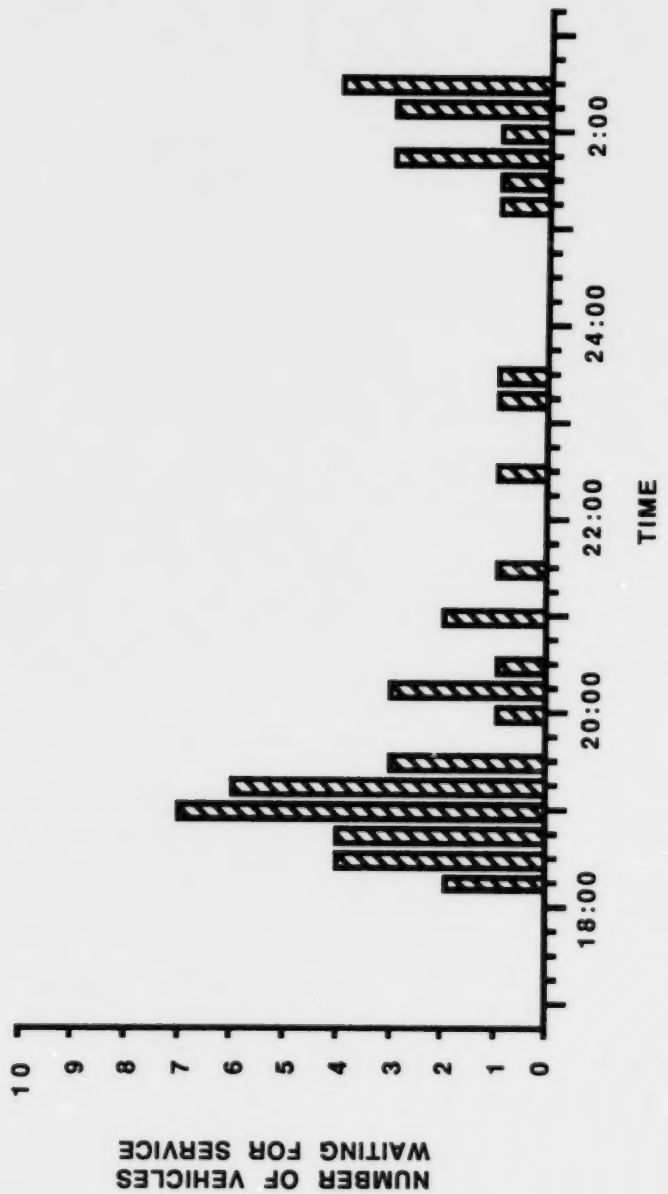

Figure 10c/ Trolley Bus Arrival at Lansdowne Garage, August 19, 1988

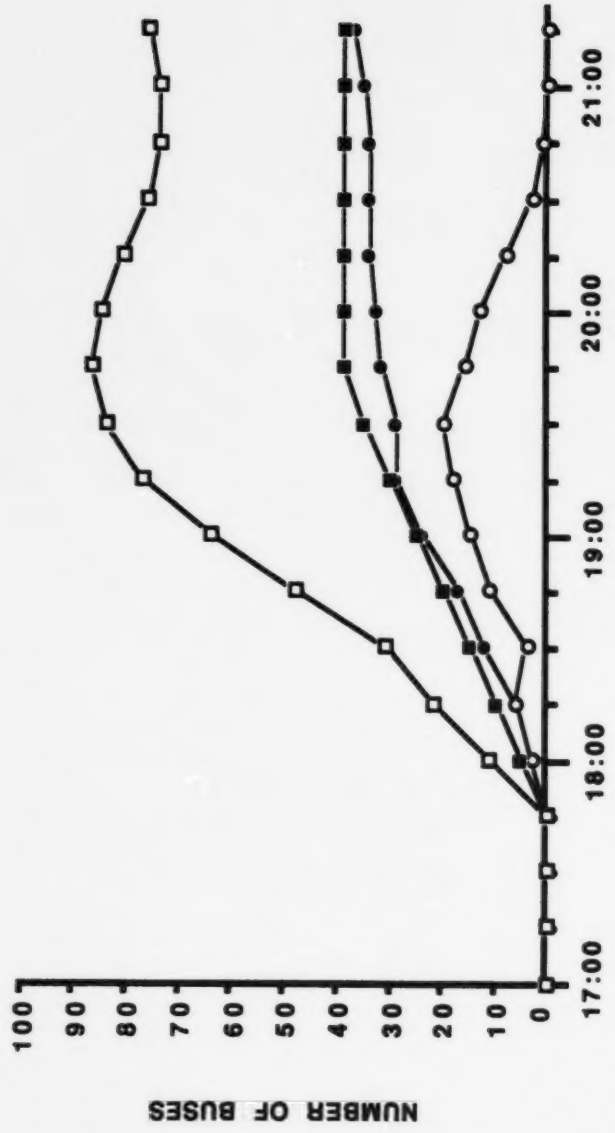

Figure 11a/ Forecast Queue Size, August 17, 1988

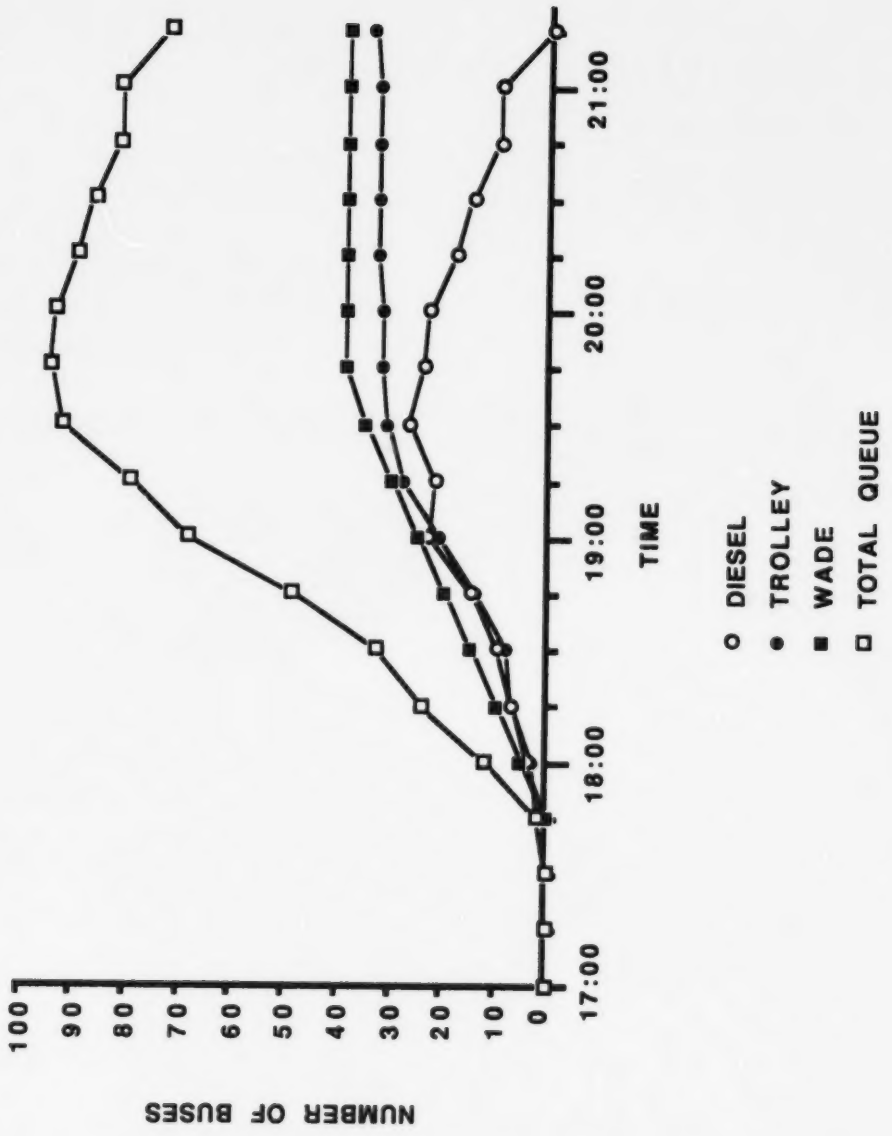

Figure 11b/ Forecast Queue Size, August 18, 1988

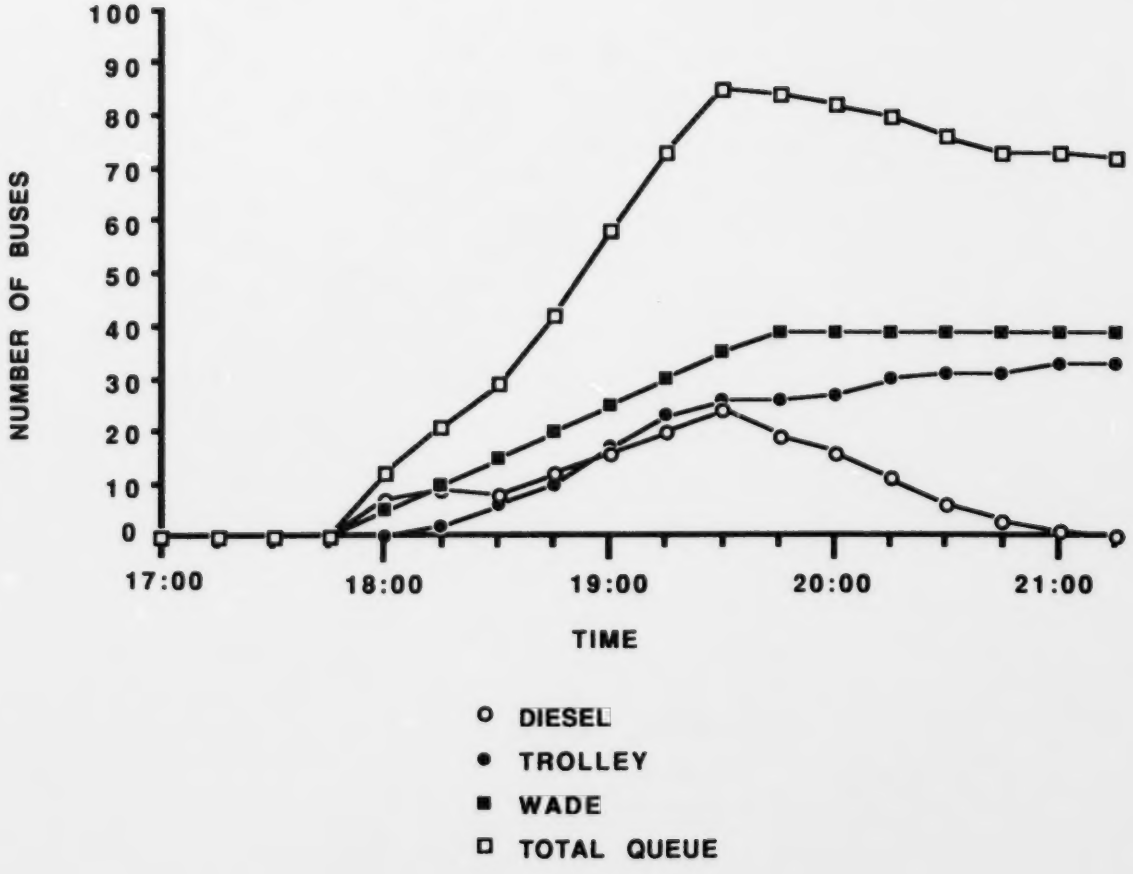

Figure 11c/ Forecast Queue Size, August 19, 1988

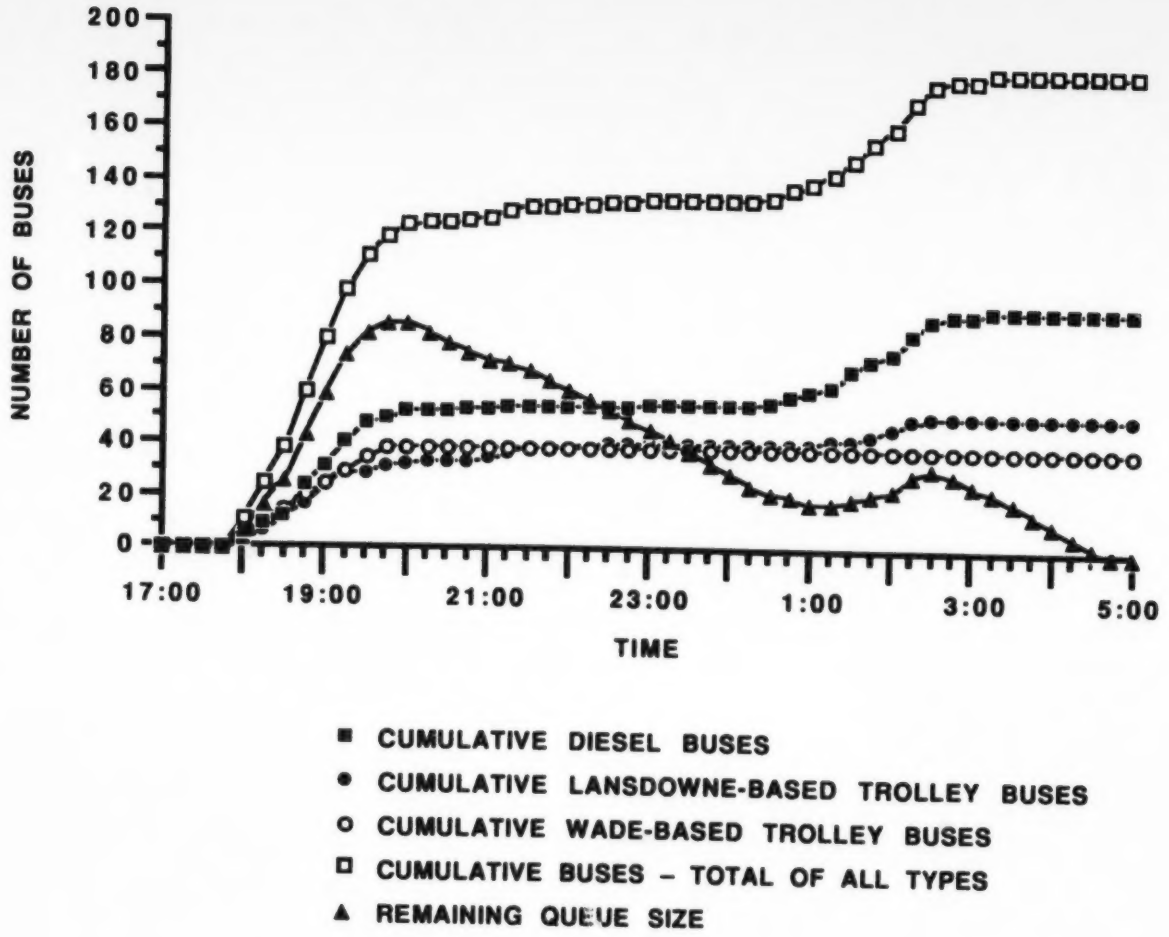

Figure 12a/ Estimated Queue for August 17, 1988 – All Buses Serviced

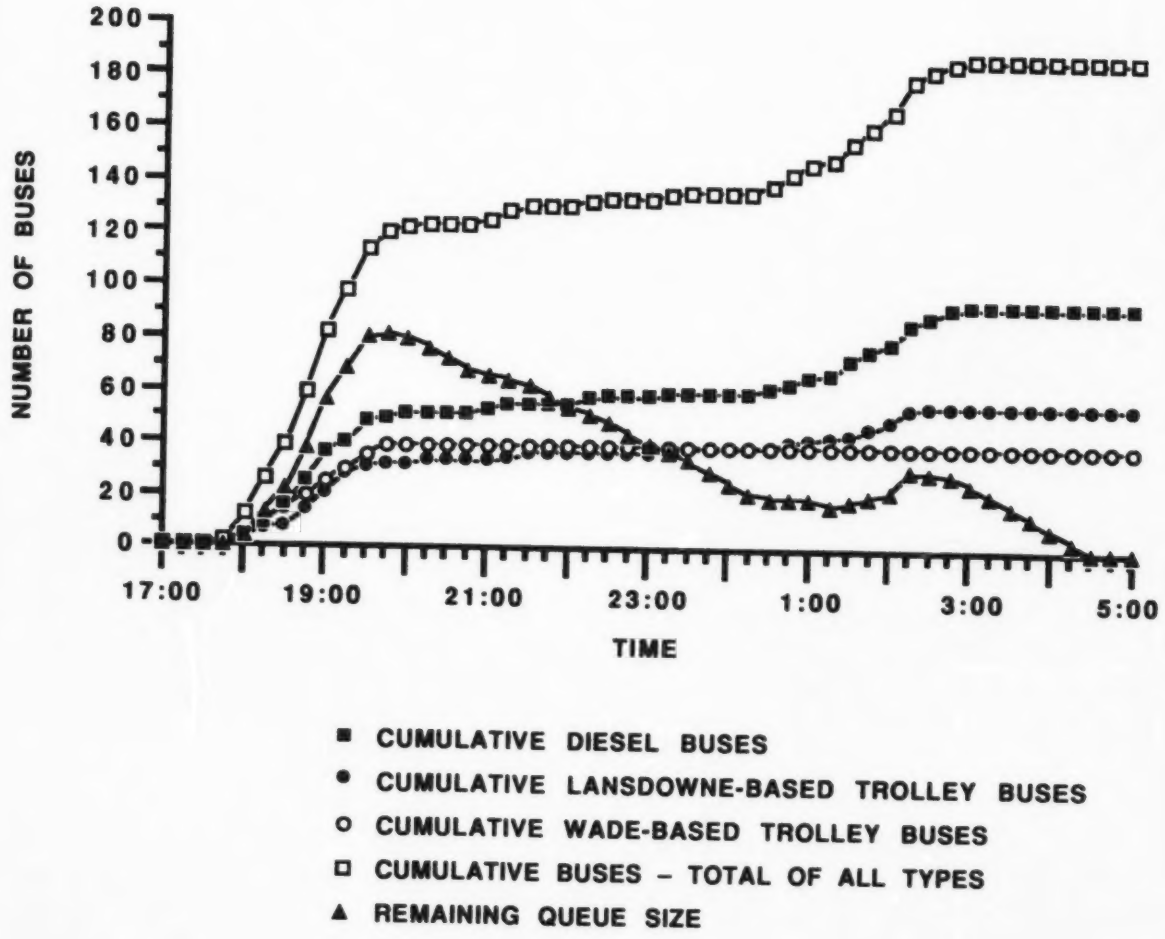

Figure 12b/ Estimated Queue for August 18, 1988 – All Buses Serviced

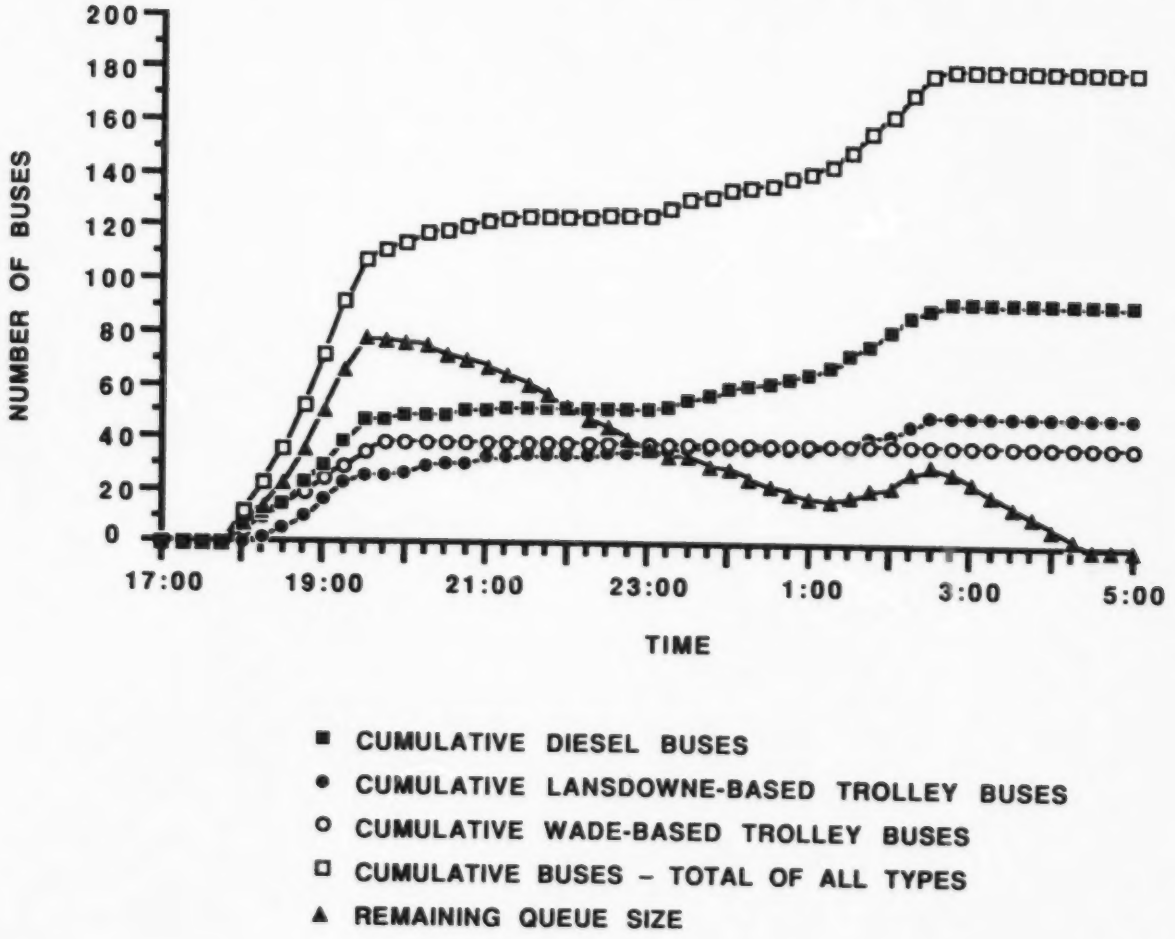

Figure 12c/ Estimated Queue for August 19, 1988 – All Buses Serviced

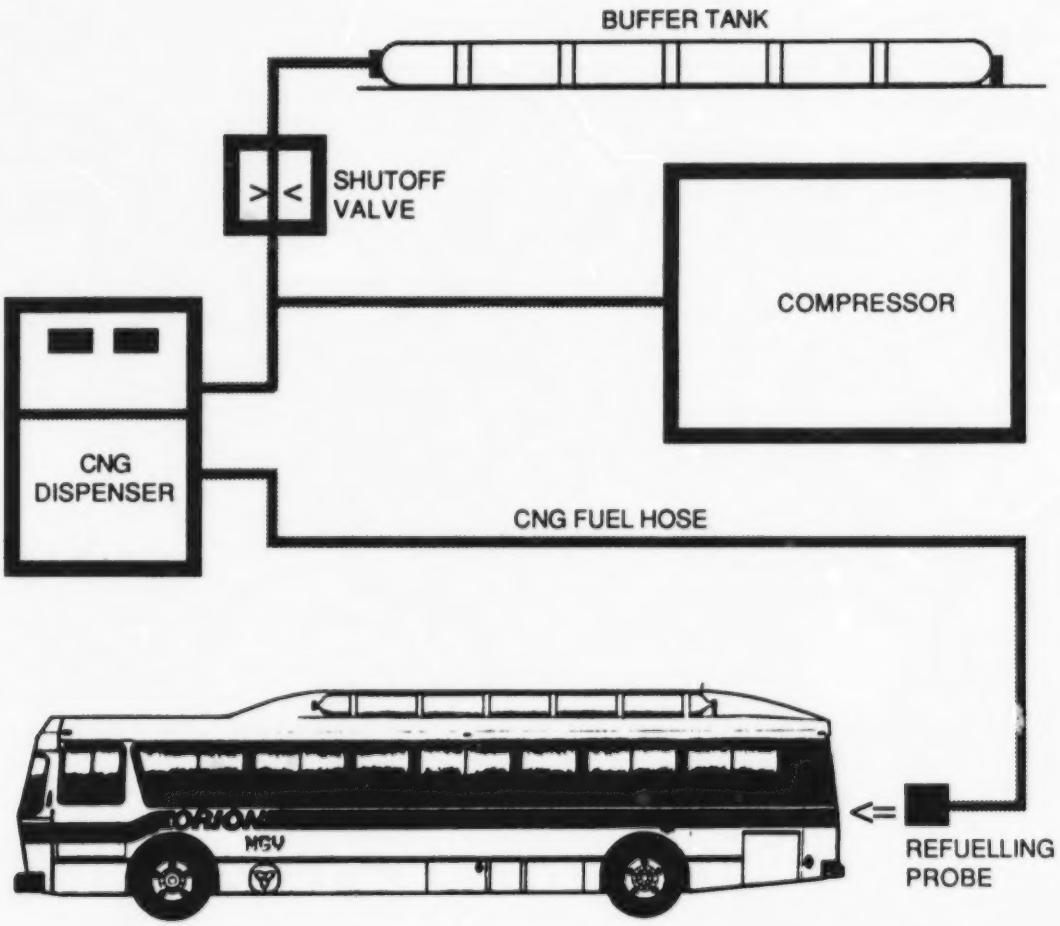

Figure 13/ Elements of Proposed CNG Refueling Station

Appendix A/ Optimum NG Compressor and Buffer Tank Sizing

A buffer tank is a storage receptacle for high-pressure natural gas. The buffer is integrated into the compressor/dispenser system as illustrated in Figure 16. During dwell periods (the time during which bus refuelling is not taking place) the compressor discharge is diverted to the buffer. This enables the compressor to continue operating with little or no disruption, while buses are being moved in and out of the servicing facility. Unwanted cycling of the compressor between the loaded and unloaded condition is also reduced.

During the filling of the next NG bus, pressurized gas from the buffer supplements compressor flow. When buffer pressure equals bus tank pressure, the buffer is isolated from the NG dispenser and the compressor continues to refuel the bus on its own. When the bus tank is full, compressor flow is again switched from the dispenser to the buffer and the cycle continues.

The two main advantages of the buffer are that it minimizes compressor cycling and enables the dispenser to deliver gas at a rate greater than compressor capacity. Correct sizing of the compressor and buffer to the application enables the refuelling time and system cost to be minimized.

The following is a preliminary exercise to estimate optimum buffer and compressor sizes for the requirements of NG buses based at the Lansdowne garage.

Buffer and Compressor Size Optimization

According to the analysis of the data obtained from the Lansdowne refuelling operation, a maximum NG delivery rate of 1510 standard cubic feet per minute (scfm) is required to match the current average diesel delivery rate. This applies to the Lansdowne operation only – it is site-specific and would not necessarily satisfy the needs of any other TTC garage.

While the diesel delivery rate is relatively constant during bus refuelling, the NG delivery rate will vary considerably. This is due to the fact that the NG delivery rate is a function of the pressure differential between the delivery source and the bus storage tank. This pressure differential is initially quite large and decreases as the refuelling process proceeds. Even if the compressor delivery rate is constant over the full range of delivery pressures experienced, gas delivery from the buffer will still vary significantly.

A typical relationship between compressor discharge rate and delivery pressure for a 400-horsepower compressor is given in Figures A1 and A2 . This curve indicates that compressor delivery is relatively constant over a broad range of discharge pressure.

To solve the optimization problem, a spreadsheet was set up defining optimum compressor and buffer size for any bus arrival condition. Initial bus tank pressure is listed in the first column, along with equivalent diesel consumption. Dwell and refuelling time from the Lansdowne study were taken as constraints on refuelling and buffer fill time. For each initial bus tank pressure, the optimum compressor and buffer size were determined, based on the following assumptions:

- Initial buffer pressure is 3600 psi. From the initial bus tank pressure the required gas delivery to the bus is determined.

- Upon connection of the probe to the bus, NG is delivered from the buffer and the compressor to the bus tank.

- When the pressure in the buffer and bus tank equalize, the buffer is shut off. The quantity of fuel delivered by the buffer is estimated. The buffer delivery time was taken as 0 seconds, to simplify the calculations.

- The compressor continues to deliver gas to the bus until bus tank pressure reaches 3000 psi. The time required for the total refuelling operation is equal to the diesel bus refuelling time, for a given fuel delivery, as defined in Appendix B (illustrated in Figure 8).

- As soon as the bus tank has been filled, the compressor is switched over to the buffer. The buffer is filled during the dwell period to 3600 psi.

Buffer and compressor size, optimized over the range of bus tank pressures expected, is illustrated in Figures A3 and A4. The maximum compressor discharge required is approximately 2636 scfm at an initial bus tank pressure of 0 psig. The maximum buffer capacity is about 8092 scf at 2200 psig initial bus tank pressure.

Since only one buffer and compressor size may be selected, it is not possible to optimize the station for all bus arrival conditions. Installation of four 500-scfm compressors will provide more than enough capacity under average bus arrival conditions. If one compressor is shut down for maintenance, there will still be sufficient capacity to handle NG buses with negligible time penalty relative to the current average diesel bus.

Source: Courtesy of Knox Western

Figure A1/ Delivery of a Typical 400-HP Natural Gas Compressor

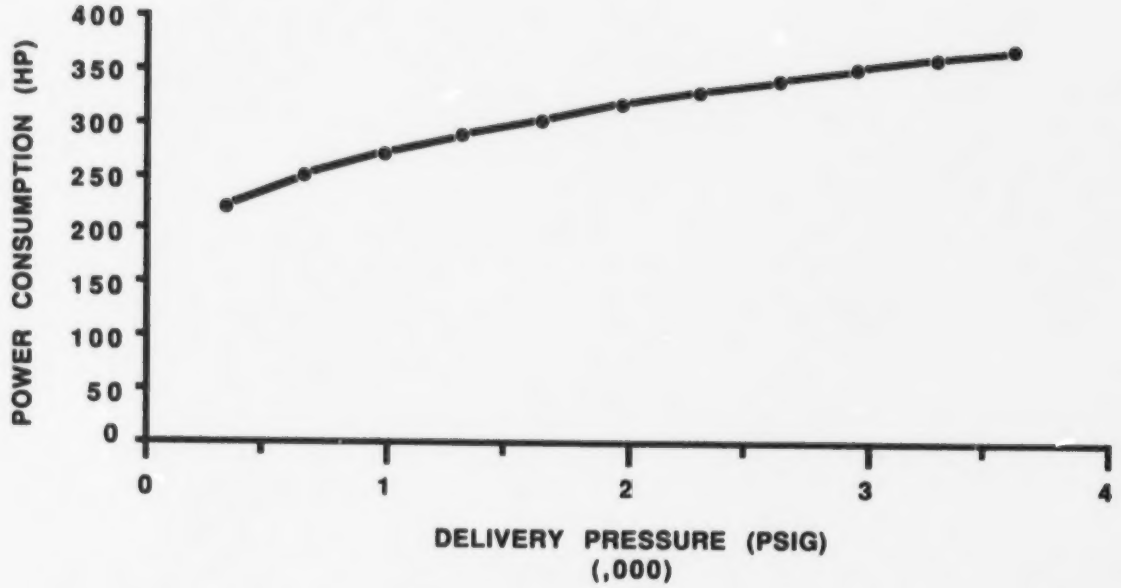

Figure A2/ Power Consumption of a Typical 400-HP Natural Gas Compressor

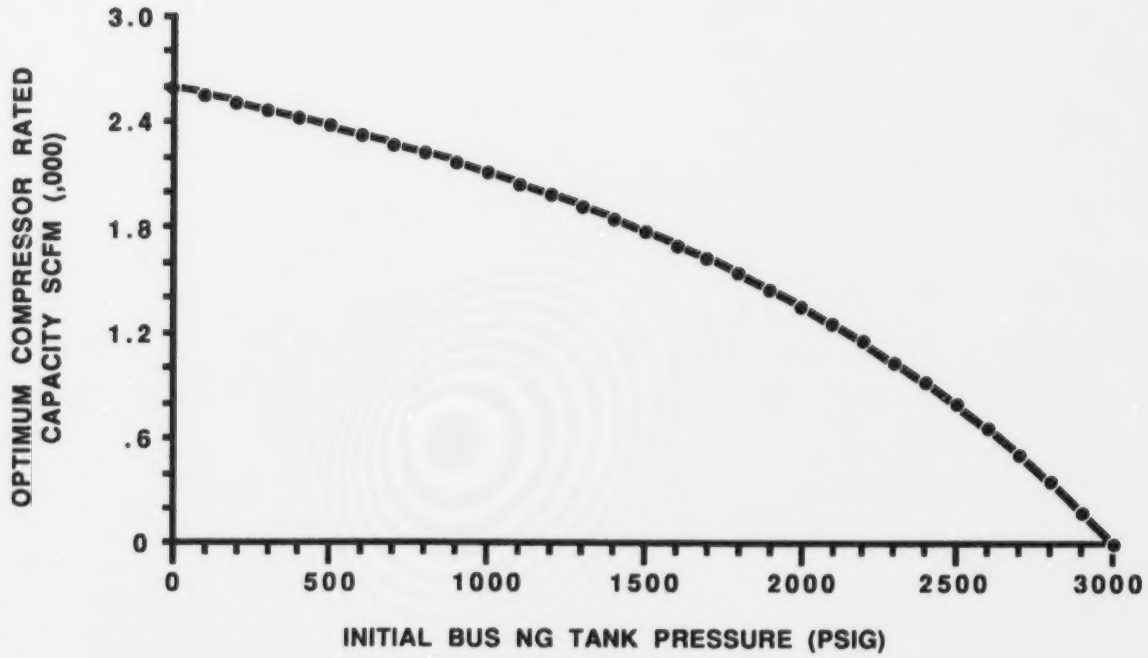

Figure A3/ Optimum NG Station Compressor Size

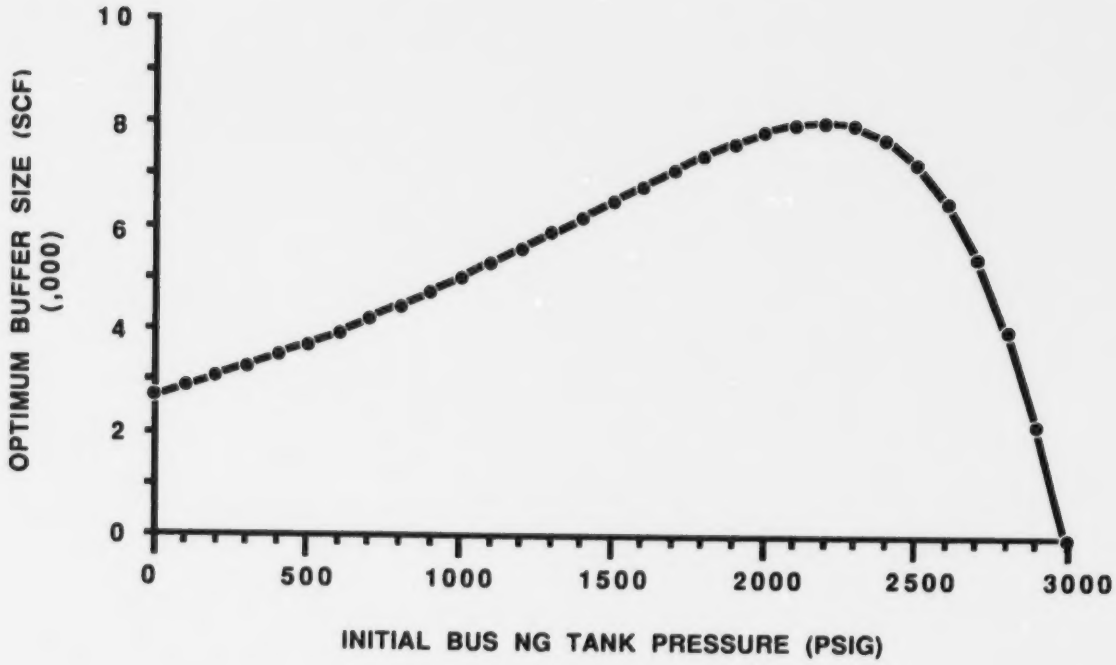

Figure A4/ Optimum NG Station Buffer Size

Appendix B/ The Relationship Between Total Service and RefuellingTime

A regression analysis was performed on the data collected at the Lansdowne garage (see Figure 8 and Table 2). The purpose was to determine the relationship between total service, refuelling, and dwell time for use in the compressor station optimization (Appendix A).

The following relationships were determined:

Total servicing time:
ts = 0.5167xVf + 144.7

Refuelling time:
tr = 0.7799xVf + 24.6

Dwell time:
td = ts - tr
td = -0.2632xVf + 120.1

Fuel delivery:
tr = 0.7799xVf + 24.6
vf = (tr - 24.6)/0.7799

Total servicing time:
ts = 0.5167xVf + 144.7
ts = 0.5167x(tr - 24.6)/0.7799 + 144.7
ts = 0.6625xtr + 128.4

Where:
ts - Total servicing time (s)
tr - Refuelling time (s)
td - Dwell time (s)
vf - Volume of fuel delivered (L)

Appendix C/ Average Service Time for a 25-NG-Bus Fleet

According to Section 5 of this report, an interim refuelling facility is proposed for the 25-NG-bus fleet, consisting of two 500-scfm compressors and an appropriately sized buffer tank. This facility would be expanded to accommodate the 125-bus operation, when approved, by installing two additional 500-scfm compressors (2000 scfm total) and additional buffer capacity (8000 scf total).

According to the analysis of the data, total compression capacity in the order of 1510 scfm will be required for an average bus. The proposed 2000 scfm is about 32% greater than that required, and exactly matching the rated capacity with one compressor shut down.

The proposed two 500-scfm compressors for the 25-NG-bus operation represent about 66% of the recommended capacity for the 125-bus operation. The following calculations estimate the average total servicing time for the 25 NG buses with total compression of 1000 scfm, and are based on equations developed in Appendix B.

Actual average refuelling time is 116.5 s (see Section 4)

Average refuelling time for 25-NG-bus fleet:
tr = 116.5x(1510/1000) = 175.9 seconds

Total servicing time:
ts = 0.6625xtr + 128.4

Average total servicing time for the 25-NG bus fleet:
ts = 0.6625x175.9 + 128.4
ts = 244.9 seconds = 4.08 minutes

Where:
ts - Total servicing time (s)
tr - Refuelling time (s)